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1.0 ABSTRACT

The following documents the technical considerations of the design of a ground based inerting system for aircraft. This system would function to further minimize the flammability of fuel tanks through the use of an inerting gas provided by a ground source to reduce the naturally occurring oxygen in the ullage (airspace) above the fuel. Reducing the oxygen content of the ullage to 10% or less inhibits the flammability of the ullage, thereby reducing the probability of a potential aircraft fuel tank ignition event.

2.0 INTRODUCTION

The design of the ground based inerting system presented here has been the result of careful examination of the technical parameters and considerations, and those parameters required and defined in the FAA Tasking Statement 4910-13; Fuel Tank Inerting Harmonization Working Group (FTIHWG). This Tasking Statement requires various means of inerting fuel tanks to be considered. While this time restraint prevented the examination of design details required for the actual inerting design implementation on a specific aircraft model, it has allowed a ground based design to be evaluated sufficiently to identify the potential benefits and complications.

The aircraft design presented here is for a system that would allow inert gas to be distributed in the center wing tanks (heated or unheated), and auxiliary tanks as requested in the Tasking Statement. Inert gas generation takes place in the airport facility and is then transported to the aircraft via pipeline or servicing truck. A servicing hose with a special interface coupling only used for the introduction of inert gas to the aircraft is utilized. Each aircraft would be certified through testing to validate the specific volume of inert gas required to reduce the fuel tank oxygen concentration to a level below that considered flammable. The Tasking Statement defines that level as 10% oxygen.

The design presented here is a generic system that would apply to any size or configuration aircraft. For the purposes of this report and evaluation, the system is defined in terms of the standard aircraft sizes and definitions derived in the previous Aviation Rulemaking Advisory Committee (ARAC) study completed in 1998. The following airplane configurations will form a standard basis for this study:

ARAC Large Aircraft

ARAC Medium Aircraft

ARAC Small Aircraft

ARAC Regional Turbofan

ARAC Regional Turboprop

ARAC Bizjet

It should be noted that because this study is concerned with the center and auxiliary tanks only, per the Tasking Statement, the ARAC Regional Turboprop is not addressed in this study since it has no center tanks per ARAC definition. The ARAC Bizjet also has no center tank per ARAC definition, but information gained late in the study became available that indicated some Bizjets have center tanks and thus they have been included in this ground based inerting study to the extent possible.

Numerous airplane configurations exist in the world aircraft community and these ARAC configurations allow a study to be conducted with configuration baselines for design and cost estimating purposes. Because there are differences between the ARAC standard aircraft and the specific aircraft designs of the world, the designs developed herein would require detail changes to actually implement into existing airplane models or future airplane models.

It should also be noted that, in general, less precise technical information was known about the structure and systems of regional turbofan, regional turboprop and business jets, as compared to the larger commercial based models. While this is not considered to be a significant issue due to the generic nature

of this GBI design and the adaptability of the design, it is noted here for reference. Also, to avoid confusion regarding the ARAC airplane class terminology, the business jets based on standard commercial airplane configurations are included with their respective commercial classes rather than the ARAC Bizjet category.

Some manufacturers may choose to approach the detail aircraft design in an alternate fashion based on their specific design philosophy. The design study in this report would not preclude these different approaches to the task. However, it has been assumed that all designs would utilize standard features for minimization of operational costs. For example, it is assumed a standard inerting gas interface for servicing would be used. The world aircraft community would utilize this standard interface configuration unless an aircraft manufacturer at some future date chooses to market a product with a different standard and impose this impact on their customer's operations. This study has assumed the servicing pressure maximum would be standardized as well to protect all the aircraft being serviced. If a manufacturer desires a new pressure standard, this new standard must include built-in features for protection of the original existing systems, both onboard and in the ground servicing equipment.

3.0 BACKGROUND

The 1998 ARAC report recommended that additional study be conducted on Ground Based Inerting (GBI) of aircraft fuel tanks to minimize their flammability. The current ARAC activity requires a detailed assessment of fuel tank inerting to be carried out to identify the issues associated with inerting airplane fuel tanks. This ARAC study examines a number of methods of inerting. The focus of this particular section of the overall report is the Ground Based Inerting system. The general design configuration that is considered the best alternative is described in detail along with the supporting arguments for the decisions made. The basic design is for gaseous nitrogen or Nitrogen Enriched Air (NEA) to be supplied from a ground based source to a servicing hose. This servicing hose would be connected to the airplane and the gaseous nitrogen or NEA would then be distributed inside the aircraft by a simple manifold to outlets in each bay or space of each affected tank. This design configuration forms the basis for the design presented here.

The designs considered here have been derived by a team with experience in aircraft fuel systems, gas production/ handling, and research in fuel tank flammability.

4.0 APPLICABILITY

The Tasking Statement for this study specifically designated this system to be applicable for all aircraft fuel tanks that are not cooled at a rate similar to a wing fuel tank. As such, there are a number of aircraft designs that are not required to have inerting systems installed in their fuel tanks by the Tasking Statement. The owners or manufacturers of those aircraft could choose to install a ground based inerting system without regulatory direction at their option.

The proposed ground based inerting system design, control, and operation are applicable to newly designed commercial aircraft, in-production commercial aircraft and in-service commercial aircraft as stated in the FAA Tasking Statement. Newly designed aircraft would incorporate the requirements of the rule to integrate the ground based inerting system during the initial design phases. In-production aircraft would require that the system be integrated into the manufacture of the aircraft concurrently with production in a manner that minimizes the impact to production, retains the certified design, and meets the requirements of the rule. In-service aircraft would be covered by Service Bulletin action with a timetable prescribed by the rule.

Auxiliary fuel tanks that are not cooled at the rate equivalent to wing tanks are also applicable to actions of this study as directed by the Tasking Statement. Auxiliary fuel tanks are typically located within either the forward or rear cargo compartment and are connected to the center fuel tank and/or center fuel tank system plumbing. Because of their location within the fuselage, shielded from the outside air stream and temperatures, all auxiliary tanks of this typical configuration are subject to this study and installation of a

ground based inerting system. These auxiliary tanks may be pressurized tanks or unpressurized tanks depending on the tank design, but both types of systems would utilize the same type of ground based inerting hardware if required. It should be stated that even though all typical auxiliary fuel tanks are applicable to this study, the schedule did not allow detailed assessment of all aircraft auxiliary fuel tank installations to confirm space is available for the provisions required for the proposed inerting system.

5.0 SYSTEM DESIGN ASSUMPTIONS

In order to perform the design and analysis for the ground based inerting system in the time allowed by the Tasking Statement, a number of assumptions have been made based on the Tasking Statement requirements with the general oversight of the ARAC Working Group. The assumptions have been documented and are explained below:

- A 10% oxygen concentration constitutes an inert tank for the sake of the exposure/risk analysis in this study.
- Oxygen concentration measurement in fuel tanks to be inerted is not necessary to ensure tank is inert to required levels.
- Aircraft will receive a minimum of 95% NEA (5% oxygen maximum by volume) from a ground source which is available upon demand at all required gate and/or operational areas.
- The discharge of NEA from the aircraft vents does not require any special precautions or procedures to eliminate any associated hazards.
- Fuel tanks to be inerted are defined by the Tasking Statement as all tanks that do not cool at a rate equivalent to the main wing tanks. This includes non-cooled auxiliary tanks mounted inside the fuselage, but not tail or trim tanks since they are located away from heat sources and are subject to exposed ambient air similar to main wing tanks.
- The airport NEA supply pressure at the servicing interface to the airplane is controlled by the ground equipment to ensure the delivered static pressure does not exceed the maximum allowable value for the aircraft type being serviced.
- For the purposes of estimating in this study, 95% NEA delivered at 1.7 times the tank volume (as demonstrated by FAA/Boeing testing on a B737NG) provides 8% ullage oxygen concentration by volume. This 8% oxygen concentration is assumed to maintain a sufficient fuel tank inert level during ground operations and initial flight operations before the oxygen concentration becomes great enough to exceed the 10% maximum required by the Tasking Statement.
- The ground based inerting system is designed to not require “scrubbed” fuel to be effective. No on-board fuel scrubbing is being provided by, or proposed for, the ground based inerting system. If scrubbed fuel is considered to be desirable or is determined to provide a cost effective benefit, the scrubbing will be accomplished by ground equipment or facilities.
- The exact NEA flow rate is not critical to ensure the required oxygen concentration on a volume basis is achieved. A wide range of flow rates could be accommodated and still achieve the required oxygen concentration in the tank. In general, system pressure, NEA purity, and total volume are required parameters instead of flow rate.

6.0 DESIGN CONSIDERATIONS

6.1 SPECIFIC INERT GAS SELECTION

A number of different gases or inert gases are available for use in the inerting task. Each of these gases have drawbacks as discussed below. The Tasking Statement specifically states that the ground based inerting system should consider using ground based nitrogen supply equipment. Nitrogen has been

identified in previous research as a good alternative for inerting. Nitrogen continues to be considered the best gas for this application. However, other gases have been examined per request of other members of the ARAC task team as a part of this study.

Carbon dioxide based systems were proposed as an alternative to nitrogen, partly because the heavier molecular weight was expected to keep the gases in fuel tanks better than nitrogen. There have been past military studies of inerting with carbon dioxide. These studies concluded the higher solubility of carbon dioxide in jet fuel would have a negative affect on fuel pump performance that could result in loss of engine fuel feed. This would introduce an unacceptable risk. In addition, inerting with carbon dioxide can result in production of carbonic acids. The potential of introducing carbonic acids to fuel tanks and the resulting corrosion potential on system components and structure was unacceptable. We have no data to indicate these concerns have been eliminated, thus we concluded carbon dioxide was not a good alternative to nitrogen. In addition, testing by the FAA and Boeing have shown the loss of nitrogen due to its molecular weight to be small, and thus not a major factor leading to the need for this alternate gas.

Use of argon gas was also proposed as an alternative to nitrogen, because its' heavier molecular weight was expected to keep the gases in fuel tanks better than nitrogen as well. Argon is currently available only in smaller quantities. Air consists of roughly 78% nitrogen, 21% oxygen and 1% argon gas. Argon production is very scarce as compared to nitrogen and considerably more expensive. Argon is very similar to oxygen in molecular size, and thus requires expensive liquefaction processes to produce. The world demand for argon gas for inerting systems would push or exceed the available supplies as well as driving the cost higher. The current cost of argon is already in excess of 100 times more than nitrogen. In addition, it is believed that argon has a higher solubility in fuel than nitrogen. There is concern that fuel exposed to high argon gas levels could result in higher dissolved gas content in the fuel which could also lead to fuel pump performance problems. Thus we concluded argon was also not a good alternative to nitrogen.

No system utilizing an inert gas other than nitrogen has shown itself to be without basic problems and drawbacks. Nitrogen and specifically NEA is considered the preferred choice for the inerting gas for a ground based inerting system. It is readily available, inexpensive, and with the emergence of membrane separation technologies, easy to use in large scale industrial applications. Nitrogen and NEA have the advantage in that they have been used in military applications for fuel tank inerting for a number of years. As such, there is some information available on its in-service performance. Not all applications have met with the reliability desired of them, but the body of information is there to better refine the inerting system designs. While NEA is readily available commercially, a drawback to nitrogen, and in fact any inerting gas for a GBI system is that its availability at airports is limited. Providing the necessary volumes required to inert the aircraft fleet will require a very large increase in gas generation capacity. That infrastructure issue is addressed elsewhere in this report. Safety is also considered a drawback for nitrogen, as with other gases that displace oxygen, since it poses confined space hazards. Even with this safety issue and the airport facilities availability issue, NEA is considered the inerting gas of choice.

6.2 BASIC INERT GAS INTRODUCTION

The method of introducing nitrogen gas into the fuel tanks was a basic design parameter evaluated. Displacement of oxygen with the inerting nitrogen is the primary requirement of the inerting system. In general, the inerting gas can be introduced into the fuel tank ullage by using the following methods:

- “Ullage washing”
- “Fuel scrubbing”
- “Fuel flow injection”
- Some combination of any, or all of these

6.2.1 Ullage Washing

Ullage washing, or the displacement of the oxygen in the space above the fuel (ullage), would give the best efficiency since the inert gases could be better directed to purge the total fuel tank ullage of gases including oxygen. This process could also be scheduled at any time during the airplane turn around. This method would require a special inert gas servicing interface and distribution system to supply inerting gases to that servicing interface. This approach does not remove any oxygen dissolved in the fuel that will evolve from the fuel during climb due to the altitude pressure decrease. Oxygen evolution does have some effect, but testing showed it to be a small impact on the oxygen level, except when the tank is relatively full. Further, when the tank is relatively full the effects of fuel consumption, which draws ambient air into the tank, causes the rapid loss of the inert levels, thus overshadowing oxygen evolution from the fuel. One could compensate for this oxygen evolution on climb by lowering the oxygen content below the 10% when inerting before takeoff to allow some room for the oxygen to come out of solution and not have the fuel tank oxygen concentration rise above the 10% maximum to minimize flammability. Directly injecting NEA into the fuel tanks through ullage washing, whether they are full, partially full, or empty is considered the best option for the basic introduction of the inerting gases onboard for a GBI system. This method would be controllable, predictable, and certifiable even though a new servicing connection is required.

6.2.2 Fuel Scrubbing

Fuel scrubbing, or the “washing” of fuel with nitrogen, is the method of processing the fuel to strip the oxygen gases out of the fuel down to levels that would not evolve oxygen above a certain level in the fuel tanks during climb. Fuel contains dissolved oxygen and as the pressure above the fuel is reduced during climb this oxygen will tend to be evolved out of the fuel into the tank ullage. Since this oxygen will raise the oxygen concentration in the ullage, the effect of replacing this dissolved oxygen with nitrogen was considered to maintain the lower oxygen levels as long as possible. Fuel scrubbing for GBI can be accomplished in two basic methods:

1. **Fuel Scrubbing Using Onboard Scrubbers and Ground Supplied NEA.** One method of scrubbing which has been used on a limited number of military aircraft types is an ‘ASPI’ type scrubber. This unit, if installed onboard, would be supplied by a ground source of NEA. This type of scrubbing generally requires a higher purity of NEA than the 95% assumed for ullage washing in this study. Assuming the scrubbing NEA supply is the same supply used for ullage washing, this requires simultaneous refueling and ullage washing to accomplish the fuel scrubbing task. If the process of scrubbing was carried out after the ullage washing, then any oxygen released during the scrubbing would dilute the NEA in the ullage if not vented elsewhere. Procedures would therefore be required. This process would also take away some of the flexibility of when the inerting operation could be carried out. It is unclear what impact, if any, this would have on the cost of GBI, but it is generally accepted that it would cost more to have this procedural requirement. It is unlikely a significant benefit would be garnered from this type of scrubbing. Although not examined in detail, this type of scrubbing unit is not considered to be readily adaptable to inerting tanks that are not refueled.

Other methods of scrubbing fuel onboard the aircraft using ground based NEA could be developed such as a specialized scrubbing manifold or other onboard scrubbing equipment. These systems are also not considered to be effective enough to justify their usage at this point.

2. **Fuel Scrubbing Using Dedicated Scrubbing NEA at the Fuel Farm or Fuel Truck.** The method deemed to be most practical is fuel scrubbing with dedicated NEA at the fuel farm or fuel truck. This method requires no additional aircraft equipment or procedural modifications to implement. It is generally considered the most cost-effective method of scrubbing as the fuel is scrubbed in bulk before deposit into the aircraft. For airport hydrant systems, a large scrubber would scrub the fuel before being pumped out of the airport fuel farm. For airports with only trucks, every truck could be

equipped with a portable fuel scrubber that is transported in tow or mounted on the truck, or there could be a central scrubbing facility at the fuel storage area where the trucks receive their fuel load.

Fuel scrubbing also effectively saturates the fuel with nitrogen which would introduce nitrogen to the fuel tanks when refueling to some degree as the nitrogen comes out of solution due to agitation. The primary means for the nitrogen to come out of solution is the ambient pressure decrease as the airplane goes up in altitude. However, as the fuel is used at altitude the nitrogen levels would not be able to keep up with the volumetric decrease in the tanks due to fuel burn, and air would be brought in via the vent system to effectively increase the oxygen levels. This system also does not displace the oxygen in the ullage when tanks are not required to be filled, or are only partially filled. This study of GBI was primarily based on center tanks and center tanks are not filled on the majority of flights due to flight lengths that are less than the maximum of which the aircraft is capable. Because of this, a GBI system based solely on refueling with scrubbed or nitrogen saturated fuel does not comply with the Tasking Statement and would not be considered effective enough for consideration especially when the additional airplane complications, airplane weight penalty, and airport complications are factored in.

6.2.3 Fuel Flow Injection

Fuel Flow Injection, or directly injecting nitrogen into the fuel as it is being loaded into the airplane also has the drawback of not inerting the tanks when the tanks are not loaded with fuel or are partially loaded. It does have the same positive aspect as fuel scrubbing of allowing nitrogen to come out of solution as the airplane is climbing, but this method was not considered acceptable for the same basic reasons as fuel scrubbing.

6.2.4 Combinations

Combinations of these methods could be utilized, but no combination has shown itself to be effective enough to consider based on either the airport facilities or airplane equipment required versus the potential gains in inerting effectivity. The limited evolution of oxygen during climb can be addressed by ways having less impact including using higher purity NEA or slightly longer NEA loading times. Flight testing also showed that ullage washing was sufficient to accomplish the inerting task. The further complication and expense of any combination is not considered required to accomplish the GBI inerting task of ensuring the tanks are inert while the airplane is on the ground.

6.3 ULLAGE GAS DISTRIBUTION

It was postulated that ullage washing could be accomplished in one of three ways:

1. Through the existing refueling manifold
2. Through the existing aircraft fuel tank vent system
3. Through a dedicated distribution manifold

It was also determined that ullage washing and fuel scrubbing in combination could be accomplished by utilizing the best method for tank ullage washing and one of two primary scrubbing philosophies if scrubbing was to be considered.

6.3.1 Ullage Washing Through Existing Refueling Manifold

It was determined that providing NEA to the fuel tanks via the refueling manifold was not practical because it precluded simultaneous refueling and inerting of fuel tanks. It was determined, due to the short turn-around time of many operational aircraft and the length of time associated with inerting a large center-wing tank that inerting and refueling would have to occur simultaneously for some operations. Precluding this would have a substantial impact on the turn-around times of certain operations. Also, introducing inert gas in this manner is not particularly efficient or desirable. The refuel distribution tube

placement is optimized for fluid flow into the individual tanks. This would not yield efficient distribution of the inert gases or efficient purging of the oxygen from the tanks. Ullage washing through the existing refueling manifold was rejected for these reasons.

6.3.2 Ullage Washing Through Existing Fuel Tank Vent System

Using the fuel tank vent for inerting was not considered viable because, similar to inerting through refueling manifold, it would provide a poor distribution of inerting gas, requiring significant increase in the amount of inerting gas required to inert a given tank. This could also have significant impact on the cost of GBI in the commercial fleet. In addition, many aircraft tanks only have one vent. This would not allow simultaneous tank venting during refueling operations and the NEA loading for inerting. It was found in testing that those tanks that have more than one vent would need to install some modification to make the multiple vent systems act like a single vent system to minimize the loss of nitrogen and the accompanying increase in oxygen concentration in the tanks. As a consequence, inerting through the existing vent system could result in over-pressurization during refueling. This has significant system safety issues for refueling operations and would require additional redesign of the vent system to maintain the existing level of refueling safety.

6.3.3 Ullage Washing Through a Dedicated Distribution Manifold

It was concluded that the preferred method for ullage washing would be through a dedicated distribution manifold installed in all tanks requiring inerting. This distribution manifold would have a dedicated servicing interface port for a NEA supply hose to be connected during ground operations. The design approach considered most effect and evaluated was a manifold with outlets mounted high in the tank. These outlets would direct the nitrogen flow throughout the tank helping to mix and circulate the ullage space for expulsion through the vent system as NEA entered the tank. This oxygen-rich ullage would be displaced out through the airplane vent system to reduce the oxygen concentration down to the required level. This design was tested in the FAA/Boeing flight tests and is the preferred option for most aircraft designs available today.

6.3.4 Alternatives for Gas Distribution

One alternative method for this would be to have the injection of the nitrogen be accomplished via a dedicated manifold located on the bottom of the tanks to allow the nitrogen to bubble up through the fuel when fuel was present. While this system has the advantage of helping purge oxygen directly from the fuel through the bubbling process, or effectively scrubbing the fuel to some extent, it also requires additional manifold plumbing be installed to help distribute the nitrogen throughout the entire tank. Without this additional manifold distribution plumbing to spread the distribution of NEA over the entire tank area, there is a potential that areas of the tanks may not reach the required oxygen level without some additional period of time to allow equilibrium to take place. It may be possible to use this design type, but implementation of the design would require careful consideration of the tank geometry to optimize the inert gas distribution in a timely manner.

6.4 SERVICING CONSIDERATIONS

A study of servicing turn around times for the standard ARAC airplane models concluded that turn around times of approximately 20 minutes for small commercial aircraft, and 55 minutes for large aircraft are not uncommon with today's operating schedules. Wherever possible, operators may also use the turn around time to recover any schedule delays. For example, they might reduce aircraft cleaning time and passenger loading times to recover time. Therefore, one aim of this system is to give the operator the greatest flexibility as to when the inerting process is actually performed so minimal delays will be incurred. This design presented here is centered around balancing minimum turn around times with the other system design requirements to minimize the impact to the airlines.

The design was developed to minimize the need for extra servicing equipment such as ladders or step stools to the maximum extent possible. The proposed sites for the servicing interface locations have been chosen to minimize requirements for special servicing equipment and minimize interference with existing service trucks and personnel.

6.5 OTHER SYSTEM CONSIDERATIONS

Another system design consideration for ground based inerting systems was to factor in the temperature effects that could effect the need to inert on a specific day. There would be no flammability benefit to inert if the temperature of the day, tank, and fuel were below those values where the fuel would become flammable either on the ground, or during the ensuing flight. While this is possible to implement, the necessary procedures would be difficult to coordinate due to delays that often occur in dispatch and departure. An additional study to determine the manner in which temperatures guidelines could be determined and utilized in-service would be required since factors such as fuel quantity, refueling sequencing, heat load from external heat sources, and ambient temperatures could influence the guidelines. If such an approach is pursued, it is not considered to significantly reduce the ground based infrastructure requirements, since most airports would still need to be able to inert airplanes due to the annual range of ambient temperatures experienced.

For tanks that are partially or completely loaded with fuel prior to flight, the consumption of fuel during flight would lead to a loss of the inert levels early in the cruise phase of flight. A method of extending the period in which the oxygen concentration level in the fuel tank ullage remains below the required level would be to provide an additional supply of NEA from onboard storage tanks. The airplane fuel tanks would be inerted by supplying ground based NEA to the servicing interface which would connect directly to the onboard storage tanks at higher pressures than the 5.0 psi maximum defined for the baseline system to maximize the tank storage capabilities. These storage tanks would feed the fuel tanks through a primary pressure regulator and a secondary backup pressure regulator for safety to maintain the 5.0 psi maximum servicing pressure. Other system complexity may be required to ensure discharge pressure from the storage tanks does not cause fuel tank pressure limits to be exceeded.

As an example, the following table gives an indication of the storage volume required to maintain the center tank on the Large ARAC aircraft category below the 10% oxygen threshold given by the Tasking Statement. The following table shows the storage volume required as a function of the initial storage pressure to maintain the ullage inert while the fuel volume is used down to 50% full assuming the tank was initially full. The estimate is also based on a gas temperature of 0 degrees C and a cruise altitude of 35,000 feet.

Storage Pressure (psi)	Storage Volume (Nm ³)
5	10
20	5.2
100	1.4

Other onboard storage tank design concerns include the additional weight and complexity of the system, the physical size of the onboard storage tanks to be effective, and the safety and maintenance issues associated with large high pressure tanks carried on board. Because of these concerns with this storage tank concept, this design possibility has not been pursued further in this study.

6.6 MMEL/MAINTENANCE CONSIDERATIONS

Per the Tasking Statement, MMEL relief will be available for situations where the ground based NEA supply is not available for airplane inerting.

The simple concept and the use of mature technology for the equipment in the system should ensure the system achieves a reliability level that is acceptable for commercial aircraft operations, without the need to build in system redundancy. This approach also means that there are only a very limited number of

failures that will prevent the system from allowing the tanks to be inerted. In the case of the more likely failures, i.e., failure of the shut off valve, maintenance procedures can be devised which will still allow the airplane to be dispatched with the tanks inerted. This aspect is considered further in the Safety Analysis Team Appendix H and the Airline Operations & Maintenance Team Appendix F.

6.7 SYSTEM COSTS

System costs are examined in detail in the Estimating and Forecasting Team Appendix G.

6.8 ENVIRONMENTAL ISSUES

The GBI system may introduce additional VOCs to the atmosphere as a result of the ullage washing procedure. Since the center tanks would be inerted every flight, the ullage and its associated VOCs from residual fuel would be exhausted out the vent system at each turn around whether the center tank was utilized or not. The detailed environmental analysis of this GBI system is beyond the scope of the Tasking Statement and is not addressed here.

7.0 GROUND SUPPLY REQUIREMENTS

7.1 NEA PURITY

Nitrogen Enriched Air (NEA) purity effects a number of different aspects of the ground based inerting system, however the primary effect on the aircraft system is one of varying the volume of NEA required to be loaded. The precise volume would be determined during development (analysis and testing) testing of the particular aircraft model and would be for a particular purity of NEA. NEA purity can also have an effect on the initial design to support the desired turn times to inert the aircraft. NEA 95% (95% nitrogen and 5% oxygen) was recommended for use in this inerting study in the beginning. Later, it was determined that NEA of slightly higher nitrogen concentration of 97 % or 98 % may be more desirable from overall cost and commercial standpoint. (See Figure 7.1-1 below). The cost of the gas is slightly higher for the higher purity, but the volume required to inert the fuel tank would be less. Consequently, the price of the total load of NEA may be lower.

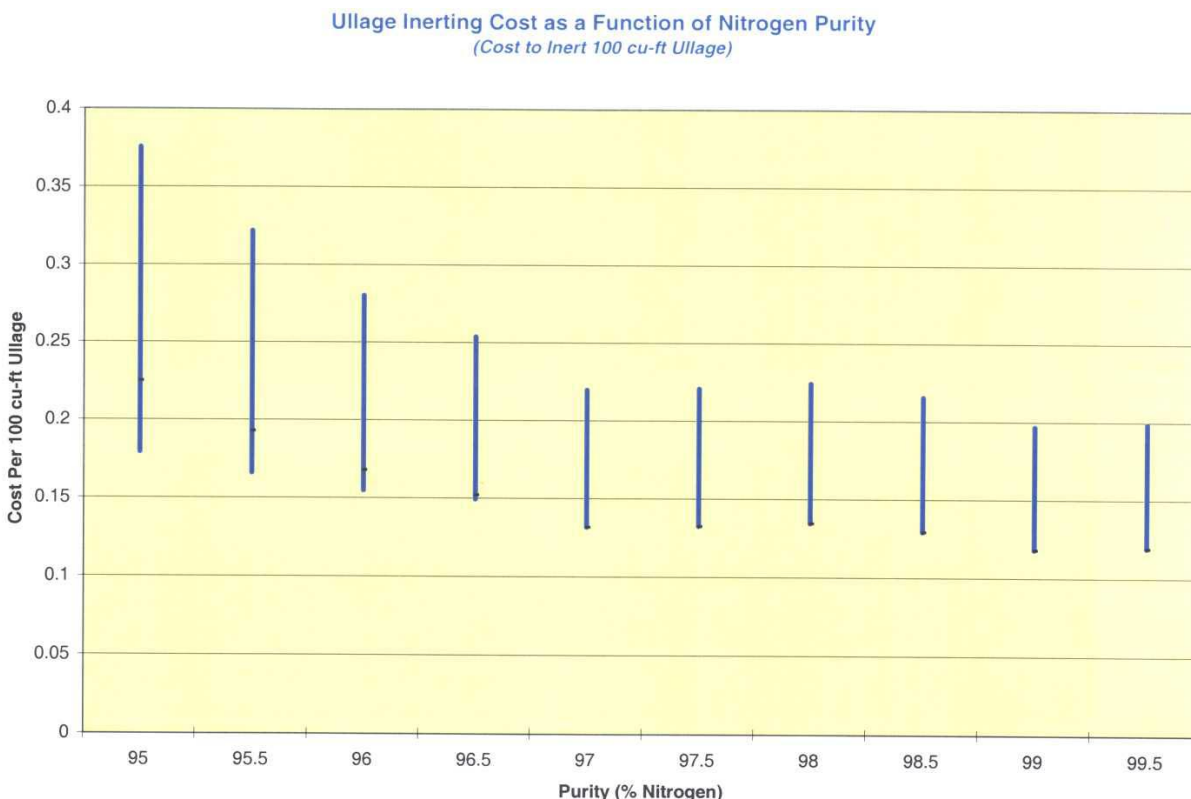


Figure 7.1-1. Ullage Cost as a Function of Purity

7.2 NEA VOLUMES REQUIRED

The volume of NEA gas required to inert the fuel tanks to a reduced oxygen level is a function of the design of specific aircraft and the detail design of the NEA manifold installed in it. Early laboratory testing indicated that the required NEA volume was 1.5 times the total volume of the tank using 95% NEA to obtain an ullage oxygen concentration of 8%. 8% oxygen was considered a good target oxygen concentration for ground-based inerting as it is below the 10% level stated in the Tasking Statement, thus allowing for some dissipation during ground and initial flight operations and some variation in the inerting process. The volume exchange necessary was refined with actual aircraft testing that was conducted on a Boeing 737NG as part of a FAA test program. That aircraft, which was modified with the installation of an NEA distribution manifold, required 1.7 times the total volume of the fuel tanks being inerted when using 95% NEA (see figure 7.2-1). As a result, 1.7 has been used for calculations in this study. It should be noted however, that this factor would vary from aircraft to aircraft due to the variations in different aircraft models and different manifold designs. Each aircraft design will require testing to determine the NEA volume required to bring the oxygen level in the fuel tank down to the required level for that airplane design. The manifold will use outlets that will be configured to help mix the ullage gases in the tank to the maximum degree possible before they are pushed out the tank vent system by the incoming NEA. More efficient mixing and purging of the ullage gases will allow the NEA volumes to be less for a given tank configuration and manifold design.

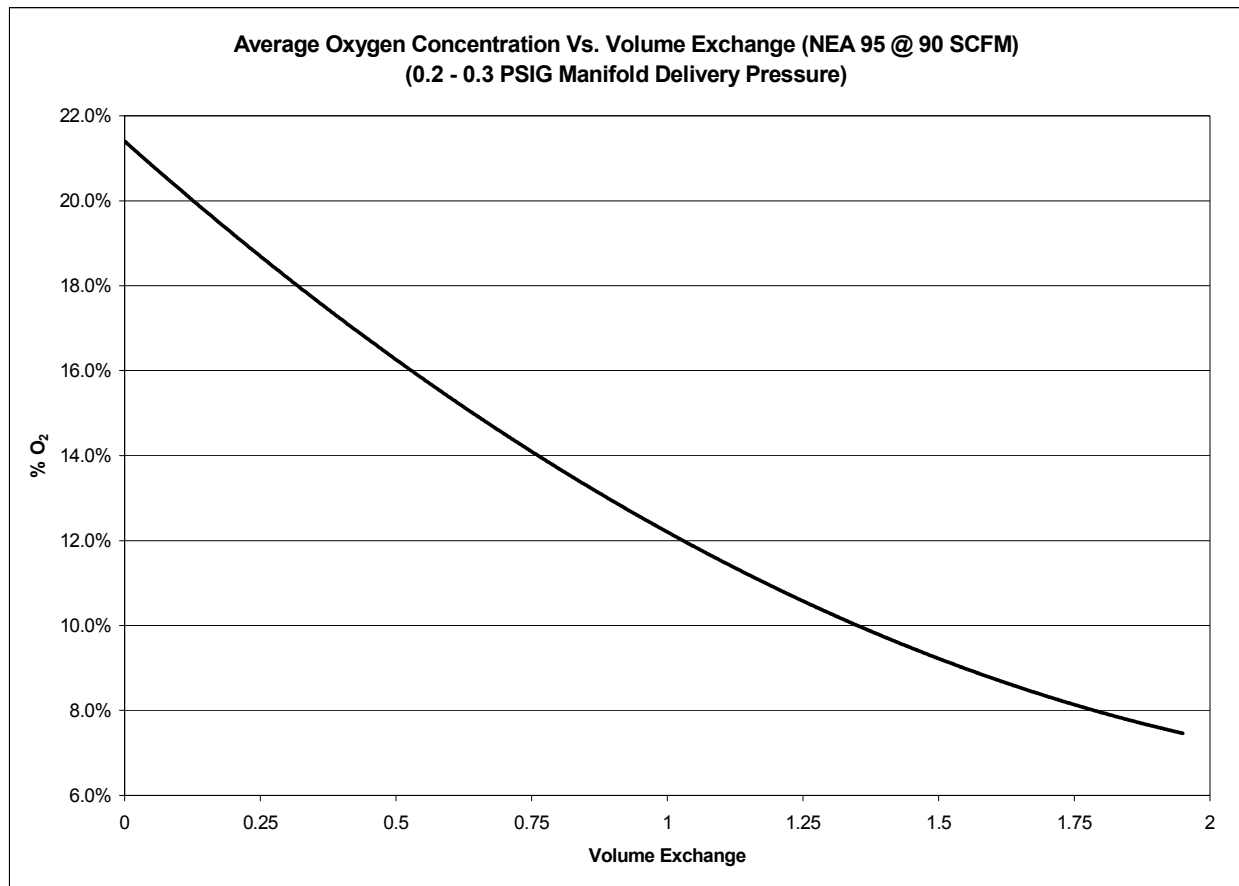


Figure 7.2-1. Flight Test Actual Purge Volume to Ullage Oxygen Content Relationship (737NG Testing)

The theoretical curves (supplied by a gas supplier) for the amount of nitrogen to purge a tank at various purities are shown in figure 7.2-2. This closely supports the actual test findings determined in the 737NG testing that took place in support of this study.

Inerting Curves for Various NEA Purities (Based on 100 cu-ft Ullage)

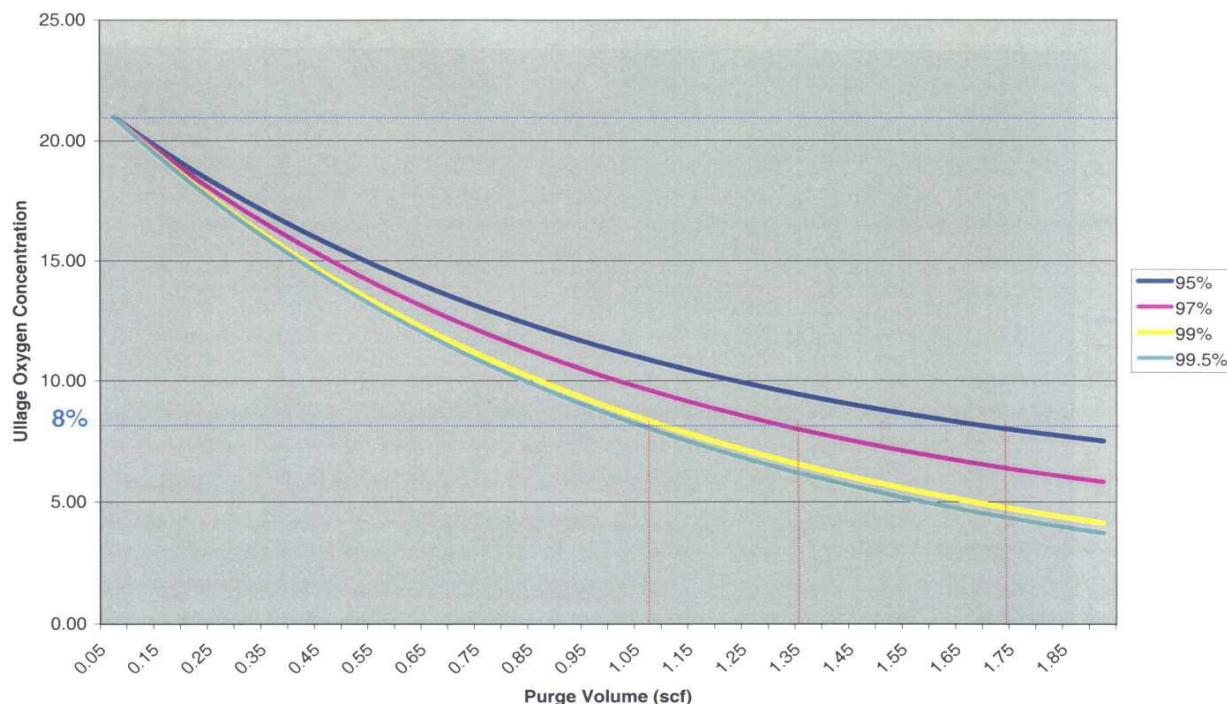


Figure 7.2-2. Theoretical NEA Purge Volume to Ullage Oxygen Content Relationship

The NEA volume required also depends on the NEA purity. A study recently performed by the FAA shows the evolution of the volumetric tank exchange as a function of the NEA oxygen percentage: “Inerting of a vented aircraft fuel tank test article with Nitrogen Enriched Air” reference DOT/FAA/AR-01/6. Inerting a tank with NEA 94% requires 1.9 volumes of NEA, as compared to requiring only 1.1 volumes with NEA 98%.

7.3 GROUND SUPPLY PRESSURE

The airport facilities supplying NEA would be required to be controlled to insure the delivered static pressure does not exceed the maximum allowable value. In order to prevent overpressurization and resulting structural damage to the fuel tank (wing), the maximum static allowable pressure has been determined to be 5.0 psi for most all aircraft. This provides a balance between aircraft structure safety for most of the world’s aircraft and the pressure required to quickly service those aircraft with a minimum turn time. All airport facilities and all ground servicing equipment would be required to deliver no more than 5.0 psi static maximum. Secondary overpressure protection must also be provided by the airport facility or ground servicing equipment to ensure the aircraft would not be damaged in the event of a primary pressure regulation failure.

Aircraft models that require the maximum pressure to be some value less than 5.0 psi static pressure would be required to carry onboard pressure regulation to reduce the pressure to the value required for that model. These models would include some models of Business Jets, some auxiliary fuel tanks, and some early aircraft models with fuel bladder cells where their maximum static pressure are typically 0.5 psi. The design of these systems would require secondary onboard pressure protection in addition to the primary pressure regulation to preclude overpressurization.

The introduction of onboard over pressure protection does have undesirable side effects. Procedures would need to be in place to regularly check for dormant failures of these devices, and the additional design issue of locating these devices where their discharge does not introduce additional hazards to the aircraft or personnel. One alternative approach would be for ground equipment to be designed to have two independent pressure supplies with mutually independent servicing interface connections. The disadvantage of this is that the equipment would require two different servicing interface connectors on each piece of NEA servicing equipment and careful design to ensure the pressure supplies could not be cross connected in any case. This extra complexity would also have additional cost implications.

7.4 GROUND BASED GAS SUPPLIES

There are several methods to produce nitrogen and Nitrogen Enriched Gas (NEA), but the two basic methods are as follows:

1. **Off-Site Production:** The classical method to provide nitrogen is the distillation of ambient air. This separation process produces high quantities of nitrogen at high purity. This scheme is generally one where liquid nitrogen is produced at a plant and it is then transported through pipelines or with trucks to the final user location. The liquid nitrogen is stored in insulated storage and it is heated and vaporized to produce gaseous nitrogen. In general, liquid nitrogen is used where high quality nitrogen and large quantities of nitrogen are desired. If liquid nitrogen systems are used for aircraft inerting, the liquid nitrogen must be in gaseous form before entering the airplane, and a temperature above the minimum certified temperature for the airplane fuel tanks and equipment.
2. **On-Site Production:** On-site production involves installation of a nitrogen generation unit installed at the customer site for production of on-demand gas. The heart of this on-site equipment is typically an Air Separation Module (ASM), composed of polymeric fibers. The driving force of the separation process is a difference of pressure between the gas sent into the membrane and the atmospheric pressure. Hence, ASMs are fed with compressed air typically powered with electricity. The gas produced is either stored in buffers or directly sent to the process requiring the gas, or in this specific case, the aircraft. This process allows production of Nitrogen Enriched Air (NEA) with oxygen contents varying from 5% to 0.1% or less. The choice of the oxygen percentage present in the NEA is made by a simple adjustment in the equipment. Flow delivered by on-site equipment can vary from 10 to 3000 Nm³/h (Normal cubic meters per hour), depending on the size of the equipment.

Numerous on-site options for the airplane inerting itself exist. One option would be to install a nitrogen generator at each concourse with distribution of the NEA to each gate through a network of pipes and hoses. For remote airplane parking or smaller airports, other options include the following:

1. Mobile nitrogen generators mounted on trucks or trailers that could be moved near the airplane for fuel tank inerting. The NEA generator would produce and feed the fuel tank directly.
2. Mobile nitrogen generators mounted on trucks or trailers combined with mobile storage. The NEA generator would continuously fill the storage and NEA is taken from the storage to inert the airplanes. This could reduce the size of the generator with a resulting decrease in power consumption.
3. Mobile storage filled at a nitrogen refilling station located at or near the airport. This solution would lead to requirements for equipment with large volumetric capacities, and the additional burden of the logistics of getting the correct amount of NEA to the airplane at the right time to support the desired turnaround time.

The details of this part of the design are considered by the Airport Facility Team. The methods for supplying nitrogen or NEA may vary around the world, but the GBI system can accommodate any method provided it has the common servicing interface and the required pressures and purity levels.

8.0 GENERAL AIRPLANE SYSTEM DESIGN

The final design of the GBI system will be aircraft specific, being dependent on the basic design philosophies/principles of the manufacturer. For this generic study, the inerting system described can be considered as one incorporating all the features likely to be necessary on any GBI system installation. They may not all be required or desired any specific design. Including all these potential features does not overcomplicate the system being described, since the overall concept remains basically simple. To keep the system simple, the approach has been to assume that the aircraft will be supplied with a fixed volume of NEA irrespective of the amount of fuel in the tank when the operation is carried out. This volume is determined during the inerting design of the aircraft. During certification tests, this volume would be supplied at a minimum NEA purity allowed and a worse case pressure. It is accepted that the required volume is a larger volume of NEA than may be theoretically necessary. This approach also ensures that the system concept is not dependent on new technologies or complex ground procedures.

8.1 GENERAL SYSTEM LAYOUT

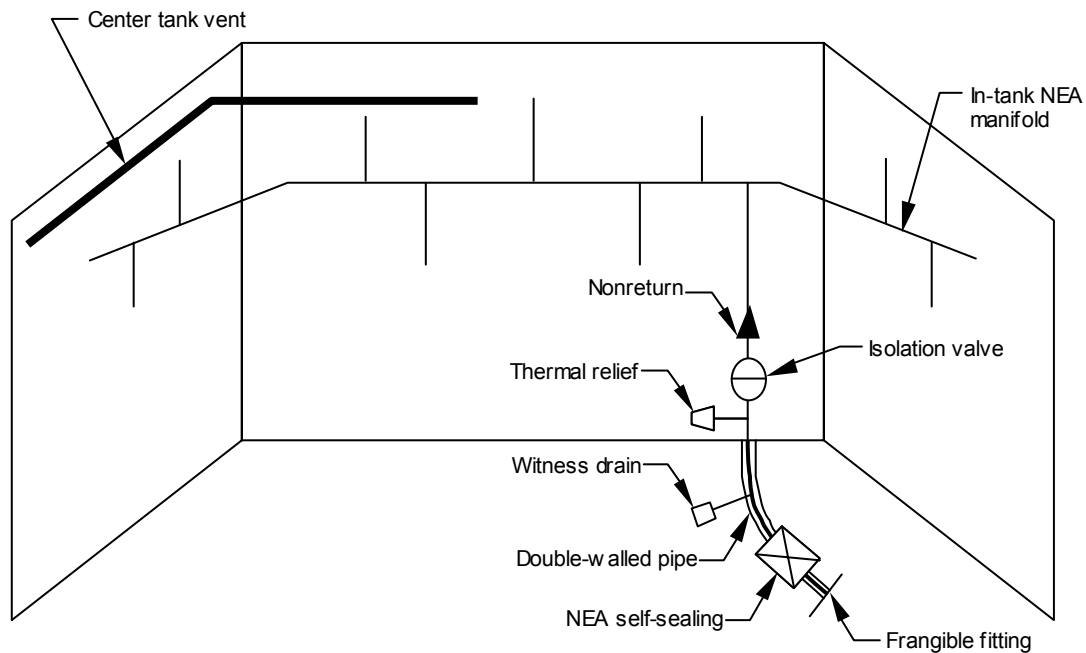
NEA will be supplied to the aircraft from a dedicated truck or distribution network present at all airports or aircraft servicing facilities. NEA will be delivered to the fuel tanks via a dedicated manifold within the aircraft fuel tanks. The review of various aircraft indicated that the type of internal structures can vary between aircraft models. On some aircraft types, the applicable tanks are divided by ribs into what can be considered as discrete cells, and in other tanks, they are basically open type structures. The internal layout and details of the distribution network to achieve the required dispersion of NEA will therefore be aircraft specific. Plumbing that is routed within the pressurized compartment or in confined spaces will be doubled walled to prevent hazardous leakage.

A valve will be mounted close to the tank wall to provide a means of isolating the internal portion of the tank from the plumbing that extends from the fuel tank wall to the NEA servicing interface. A second valve for redundancy maybe required, and these may be either manual valves, electrically actuated valves, or check valves or a combination depending on the features desired. This portion of plumbing must also be carefully designed to minimize the potential for fuel spillage after damage from a gear-up landing. This plumbing most likely will be routed up as far as possible and then back down again either inside the tank or outside the tank in an attempt to keep fuel from collecting at the servicing interface from normal operations. This portion of plumbing would be double walled if it is mounted in an enclosed space for personnel safety. A witness drain would be installed either as part of the servicing interface coupling assembly or very near the servicing interface to identify when the valves are leaking between the tank and the servicing interface. A second witness drain would be installed to confirm the integrity of the double walled plumbing.

Drain valves may be necessary in the manifold design to keep fuel from collecting in the manifold and preventing the expected NEA flow characteristics. This would not be a recognizable fault to the servicing person. Careful evaluation of the pressures available and the potential for a fuel-plugged areas would be required. Consideration for water collection and freezing would also be required when evaluating for the installation of drain valves and their placement.

Design of the manifold may include shaped and sized nozzles to better direct the NEA for more efficient purging of the tank. Other designs may only require an outlet cut to a certain size in the plumbing. These details are not addressed in this report other than to recognize them as design options.

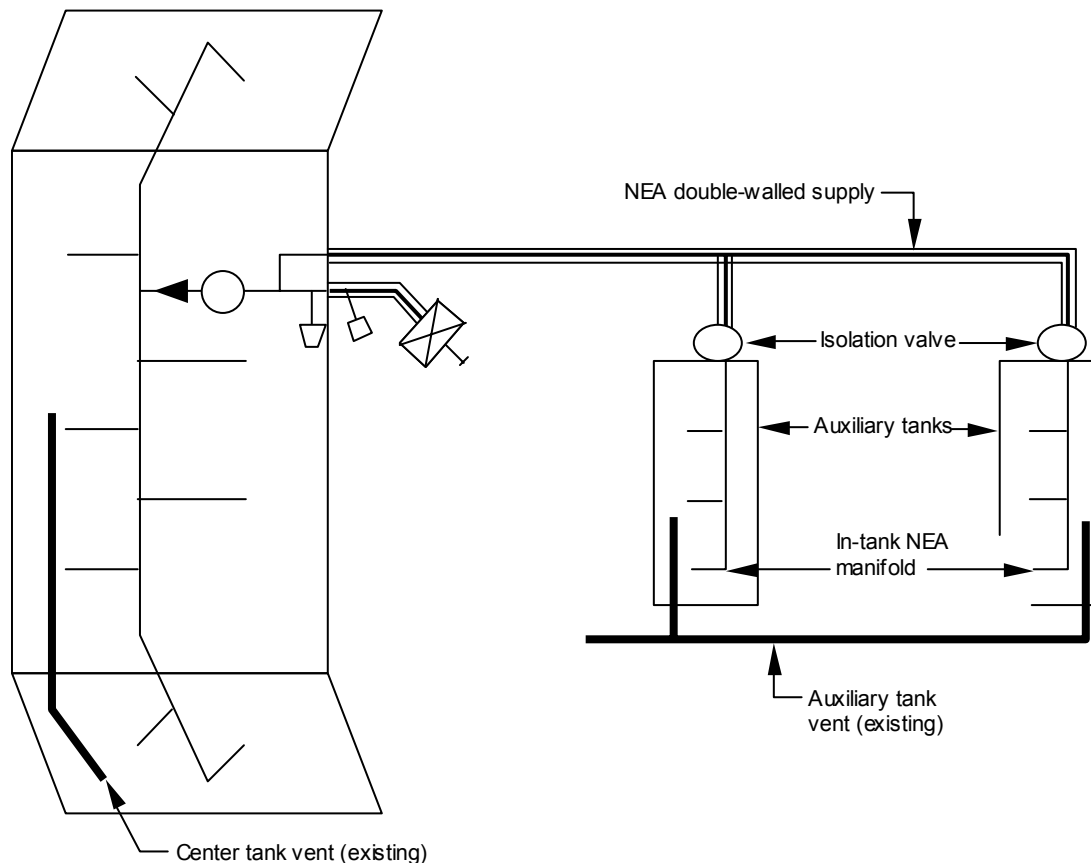
The schematic for a standard configuration aircraft is shown in Figure 8.1-1.



297925J2-045

Figure 8.1-1. System Schematic for Airplane With Center Wing Tanks

Auxiliary fuel tanks, when installed in the aircraft, will be serviced with NEA from the same servicing interface location. A schematic of the system for an airplane with auxiliary fuel tank(s) is shown in Figure 8.1-2.



297925J2-046

Figure 8.1-2. System Schematic for Airplane with Auxiliary Fuel Tank(s)

8.2 SERVICING INTERFACE

The ground based inerting design requires development of a new airplane servicing interface for the NEA servicing hoses. This new design would preclude interconnection of other servicing hoses or devices to protect the various airplane systems including the inerting system. The potential design would incorporate a frangible self-sealing coupling interface to prevent damage to the aircraft in the event the hose or coupling itself is forcibly removed. The servicing interface would be designed to not pose a safety hazard if any part or the entire servicing interface assembly and/or installation is damaged or forcibly removed from the aircraft, as in a wheels up landing.

8.3 SERVICING PANEL LOCATION

The new service panel will be located in the aircraft to accept the new NEA servicing interface coupling and hose. Due to this study being limited in scope to center wing and auxiliary tanks, the NEA servicing interface location has been located near the fuselage of the aircraft to minimize tubing installations. However, the specific location of the NEA servicing point will be a detail design task for each aircraft type. The location should be chosen to minimize system design and aircraft structure impacts, as well as, providing as much consideration for other servicing efforts being carried out in the same area. Most notably, interference with baggage handling personnel would need to be minimized. The ATA has suggested that small/regional aircraft would prefer the NEA connection on the aircraft right side, and all other aircraft would prefer the servicing location be on the left side. The location should also be chosen to

minimize the safety hazard if any part or the entire servicing interface assembly and/or installation is damaged or forcibly remove from the aircraft.

Other locations considered did not exhibit desirable servicing environments. Landing gear attached locations are not desirable due to the complexity of plumbing and equipment in a harsh, moveable environment. Location towards the front or rear of the fuselage is not desirable, as additional tubing is required to connect to the center wing tank adding routing complexity and system weight. Rear fuselage locations also may be further from the ground in many models requiring other ground equipment like ladders or step stools. Wheel well locations are not desirable from a personnel safety and aircraft safety concern. If the servicing panel is mounted in the wheel well area, additional personnel training would be required to allow entry due to the complexity of the equipment in the area. The wheel well areas are also more confined, and as such, hold more risk for personnel due to the potential for a confined space exposure to undetectable gases including NEA. The servicing point should also be located so as to facilitate the easy movements of the NEA servicing personnel to the maximum degree possible. Presently it is believed that the wing-to-body fairing under the wing provides the most reasonable site for the NEA servicing location. Other locations may be more suitable on smaller aircraft. The addition of a servicing panel door in the fairing would be required in this location, but may not be required in all locations depending on the airplane design. This location was also chosen to minimize the wing structure impact and simplify the design for in-service and production aircraft installations by minimizing the plumbing runs in the wing to hookup to a wing mounted servicing interface

8.4 GENERAL SYSTEM DESIGN ANALYSIS

The ground based inerting system has been sized to load the required NEA volume in the generic sized ARAC configurations in the following times:

ARAC Large aircraft	20 minutes
ARAC Medium aircraft	15 minutes
ARAC Small aircraft	10 minutes
ARAC Regional turbofan	10 minutes
ARAC Regional turbofan	----- (not fitted with center tanks)
ARAC Bizjet	10 minutes -- (ARAC and most not fitted with center tanks)

These times do not include time to connect/disconnect the ground equipment. The time to connect is projected to be no more than 5 minutes, and the time to disconnect and provide paperwork to the pilot is projected to be no more than 5 minutes, or a total of 10 minutes per aircraft NEA servicing. These times were chosen to eliminate or minimize any gate delays to allow for short aircraft turn times. Longer times would not significantly change the aircraft design cost, but could provide less impact to existing aircraft structure due to the decrease in the required diameter for the NEA manifold and tubing. Airport Facilities will need to optimize the airport capability to handle the peaks through equipment sizing or accumulators. (See the Airport Facilities appendix)

The general GBI system was analyzed to estimate the flow performance with typically sized tubing and manifolds. As would be expected, the performance depends on a number of parameters that can be varied. Those parameters included the tubing and manifold diameters, the tubing lengths, the flow velocities, the various fuel tank volumes, NEA flow rates desired, and time to complete the required servicing. Tubing and manifold diameters were kept as small as practical to keep to minimize the structural modification and weight aspect of the design as much as possible. The tubing lengths are a function of the tank configuration and size of the specific model. The flow velocities were minimized to be consistent with existing Environmental Control System (ECS) recommendations to minimize erosion, noise, and other

adverse gas flow effects. The volume of each fuel tank was determined and multiplied by the number of volumes required to reduce the oxygen content to 8% or below as determined by flight testing. That number was determined to be 1.7 times the ullage volume as described elsewhere in this Appendix. The various ARAC airplane configurations with and without auxiliary fuel tanks were estimated to have the basic manifold plumbing lengths and diameters in figure 8.4-1.

Model	Manifold Length-Total	Diameter
ARAC Large aircraft	75 feet	2.0 inch
ARAC Medium aircraft	50 feet	1.5 inch
ARAC Small aircraft	25 feet	1.0 inch
ARAC Regional turboprop	15 feet	0.5 inch
ARAC Regional turboprop	not included	Not included
ARAC Bizjet	15 feet	0.5 inch

Model	Length between center tank and aux tank	Diameter	Manifold Length-Inside tank	Diameter
ARAC Large aircraft with aux tank	50 ft double wall external to tank	2 in internal diameter/3 in external diameter	15 ft inside tank	2 in diameter
ARAC Medium aircraft with aux tank	50 ft double wall external to tank	2 in internal diameter/3 in external diameter	15 ft inside tank	2 in diameter
ARAC Small aircraft with aux tank	42ft double wall external to tank	1.5in internal diameter/2.5in external diameter	13ft inside tank	1in diameter
ARAC Regional turboprop aircraft & ARAC Bizjet aircraft with aux tank	30ft double wall external to tank	1.0in internal diameter/2.0 in external diameter	10ft inside tank	1in diameter

Figure 8.4-1. System Manifold Lengths and Diameters

This design information was used to model and analyze the basic system for overall system performance. The results were then utilized to balance the design within the desired turn around times.

8.5 GROUND AND FLIGHT TESTING EXPERIENCE

Ground and flight test was performed on a B737NG airplane in February of 2001 to better understand the issues applicable to the ground based inerting system. A temporary inerting system was installed in a customer's new B737NG prior to delivery. System installation and testing was performed over several weeks. The test airplane was equipped with instrumentation to record pertinent variables for future analysis. Oxygen sensors were installed in eight locations to sample the ullage space in the center tank of the airplane. The system required considerable review and analysis to confirm it was safe for personnel and the aircraft. NEA was supplied by a ground based NEA generator located adjacent to the airplane. By changing the two primary variables, fuel load and NEA loading sequencing, various GBI system scenarios were run to further understand the impact of the primary variables. Tests were also performed to better understand the impact of having a fuel tank with multiple vents. Testing did not use scrubbed fuel.

Testing has shown that multiple center fuel tank vents can result in the flow of ambient air through the tank ullage and result in the loss of the desired inert oxygen levels after the NEA inerting process (see figure 8.5-1). Local wind and certain flight situations accelerated this loss. All airplane designs that utilize more than one vent per tank may exhibit this behavior. When one of the two vents installed on the test airplane was blocked, the ability to retain the desired oxygen level was considerably enhanced. The test airplane maintained an oxygen level below 10% through taxi, takeoff, climb, and into cruise (see figure 8.5-1).

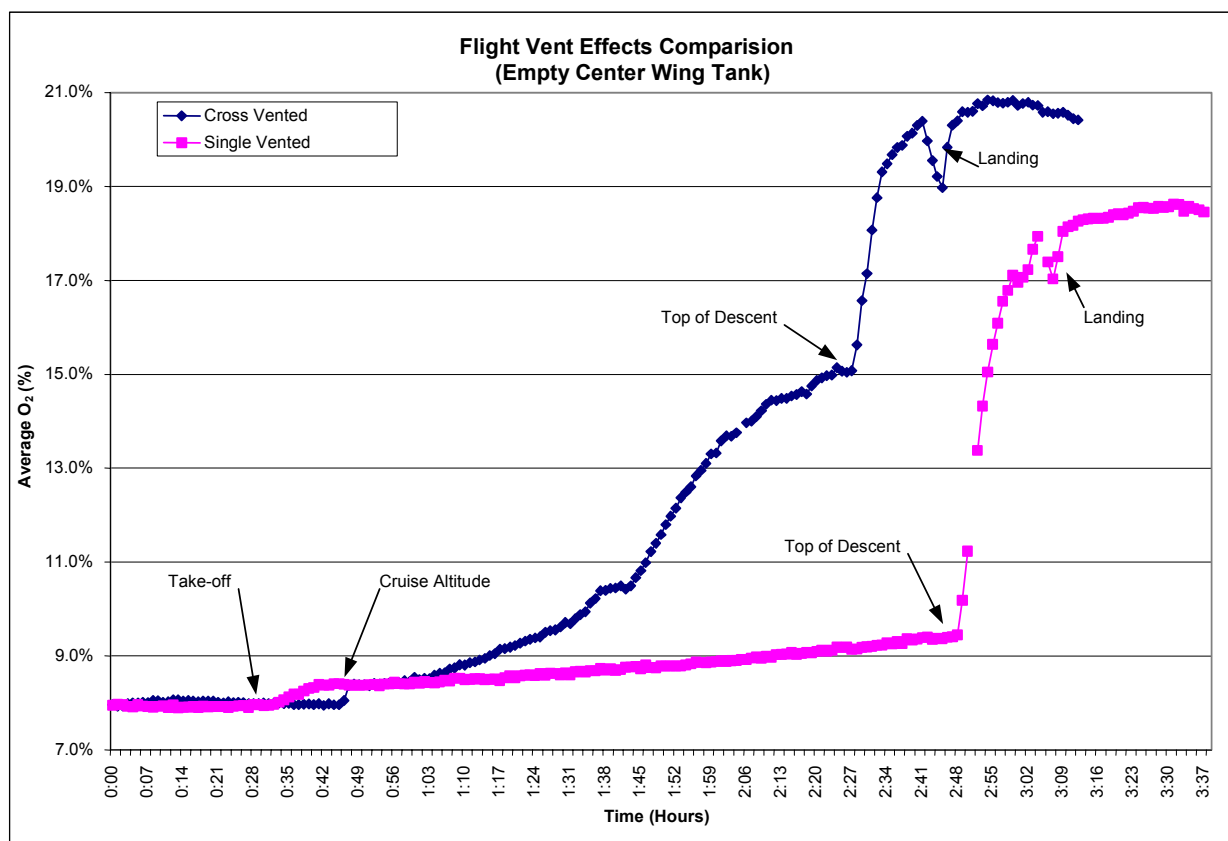


Figure 8.5-1. FAA/Boeing (B737NG) Flight Test Results Showing Effects of Crossventing

Testing also showed the evolution of gases out of the fuel did occur as the altitude increased. This effect did not induce a significant oxygen level change when fuel levels in the CWT were low (i.e., less than 20%) at takeoff. Fuel scrubbing could reduce this effect. However, because the CWT is the last tank typically filled and the majority of flights occur with low or empty CWT fuel levels, the majority of flights would not benefit from fuel scrubbing. Further, CWT's with high fuel levels at takeoff lose their inert levels early during cruise due to ambient air in-flow to replace the fuel consumed. Thus, fuel scrubbing would only slightly change the GBI fleet exposure analysis of tanks with high fuel levels at takeoff. Overall, it was concluded fleet wide GBI performance would not be significantly enhanced by the use of scrubbed fuel.

Testing also showed that there was some difference in the oxygen levels when the sequencing of the NEA gas loading was changed around the refueling event, but here again it was not considered to be significant enough to impair the system. The ability to be able to have the GBI occur at any time in the airplane ground turn around time independent of the refueling was demonstrated.

8.6 SYSTEM CONTROLS

A control panel near the NEA filling point would be provided. This panel would contain the following items:

1. A switch to operate the NEA isolation valve for each tank, if installed
2. An indicator light for each valve, if installed
3. A placard clearly indicating the required volume of NEA, purity, and pressure requirements

Additional control of the NEA tank isolation valve may also be required depending on airplane system details and the supply pressure of the NEA. This control would cause the inlet valve to close under refuel overflow conditions thus limiting any tank over-pressure condition.

Certain Auxiliary tank configurations would require specific manual procedures to supply each tank with a suitable quantity of NEA during the ground operation to minimize the amount of NEA to be supplied.

8.7 SYSTEM OPERATION AND SERVICING

The system may be operated at any time throughout the aircraft gate time available. The system may be operated before the refueling operation commences, during the refueling process, or after the refueling process has ceased. The quantity of NEA will be the same by definition in any refueling scenario to simplify the NEA servicing processes.

One particular quantity of NEA at a specified pressure range will be required for each aircraft model. Supplemental Type Certificates (STC) or other modification involving the fuel system may require different amounts of NEA for similar aircraft and this must be clearly defined on placard at the NEA servicing location and in the Airplane Flight Manual. Detailed operational differences of the GBI system may be slightly different between manufacturers, but the intent is for them to be similar in operation.

A printed NEA flowmeter output receipt would be provided to the pilot at the end of every NEA servicing provides the check that the NEA has been loaded and the volume loaded is correct. The ideal NEA flowmeter system would print the quantity, minimum purity and minimum pressure for the pilots' comparison to the AFM.

Future aircraft designs may utilize a more sophisticated control over the NEA servicing activity, including the volume of nitrogen delivered. Onboard aircraft computers and information from the ground based equipment could work together to optimize the NEA delivery particularly when the NEA is added after refueling. Ground equipment manufacturers and facilities designers may want to work with the aircraft manufacturers to ensure this option is made possible and interface requirements are defined. That detailed definition is out of the scope of this study.

Typical NEA servicing instructions:

1. Open access panel.
2. Verify servicing equipment/source meets aircraft placard requirements for pressure and NEA purity.
3. Connect the servicing hose with the aircraft NEA servicing location and lock in place.
4. Select the isolation valve open. Verify indicator light illuminates confirm valve has opened.
5. Add required volume of NEA as identified on the placard.
6. Close isolation valve and verify indicator light extinguishes.
7. Unlock and disconnect NEA servicing hose coupling.
8. Fill in control sheet to indicate operation has occurred and amount of NEA added if not printed in sheet by flowmeter.
9. Verify the volume delivered meets or exceeds the required volume on the NEA servicing placard.
10. Deliver NEA servicing sheet to the flight crew.

8.8 AUXILIARY TANK DESIGN ISSUES

For aircraft fitted with auxiliary fuel tanks, system operation and equipment arrangement for inerting the tanks would be similar to that for a center tank installation. Aircraft with center tanks and auxiliary tanks installed would utilize a common NEA service interface connection and associated controls. The procedures to inert the auxiliary fuel tanks would be the same as the center tank, except for the potential

difference in NEA volume required. The aircraft plumbing would be arranged to split and balance the incoming NEA flow so that each tank receives the correct volume of NEA. This would allow the auxiliary tanks to be inerted at the same time as the center tanks to minimize impacts on turn around time. It also may be possible to use the auxiliary tank refueling line for inerting due to the configuration and smaller size of the tank. Certification testing would be required to show proper inerting in all tanks.

The plumbing between the center tank and the auxiliary tanks (in all locations within the pressurized cabin area) must be double walled to preclude NEA leaks from entering the pressurized passenger area. In addition, the introduction of the ground based inerting system for aircraft auxiliary tanks would require modifications to cargo compartment panels, linings, and new rubber auxiliary tank liners where so equipped. Additional penetrations will be required through structure and the center wing tanks to route the required tubing to deliver NEA to the auxiliary tanks.

Suppliers of auxiliary fuel tanks that are not covered under the original airplane certification must obtain a Supplemental Type Certificate (STC) to install an auxiliary fuel tank system. If properly integrated, the fuel tank distribution manifold and auxiliary tank NEA distribution system would be interconnected to utilize a single servicing interface location. The auxiliary tank system would be designed such that the inert gas supplied by the ground system at the single servicing interface location provides sufficient NEA to inert the auxiliary tanks and the normal airplane fuel tanks with no additional interaction by ground personnel. The actual volume of inert gas required would be determined at certification and would be clearly shown on the placard directly adjacent to the servicing interface location. Other systems may be possible that include automatic sequencing of the inerting system valves to control the NEA distribution. These interactive systems would be required to demonstrate that they meet the applicable requirements at certification while minimizing servicing personnel induced error.

STC providers would be solely responsible for showing that the original airplane inerting system certification was not degraded when the STC auxiliary tank(s) were fitted to the modified airplane. This may include conducting the complete airplane inerting certification testing over to verify the total airplane inerting system meets the applicable requirements. New placards showing the new NEA volumes would be required at the servicing interface location. Auxiliary tanks fitted by the original airplane manufacturer prior to certification would be covered as part the routine certification process.

8.8.1 Auxiliary Tank Pressurization Alternative

Some auxiliary tank designs reviewed transfer fuel using pressurized air. Pressurizing the tank means that the tank ullage is effectively at a lower altitude. This results in a higher fuel LFL and thus a higher fuel temperature is required to produce a flammable atmosphere within the tank. Therefore, an alternative method of achieving a lower flammability exposure for auxiliary tanks may be to increase the pressurization level in the tanks at all times, or convert tanks which are open vented, to pressurized systems. Application of this technique may show that the resulting flammability exposure is similar to that which would have been achieved by inerting (see discussion of auxiliary tanks in Flammability Exposure Analysis Appendix J). In order to provide this alternative, all design factors and considerations affecting the design and safety must be addressed including, but not limited to, structural considerations, venting, loss of cargo bay pressurization, etc.

9.0 EQUIPMENT REQUIRED

The following equipment is required for inerting with a ground based inerting system:

9.1 NEA SERVICING INTERFACE

As stated earlier, the ground based inerting design requires development of a new airplane servicing interface for the NEA servicing hoses. A new worldwide engineering standard for the servicing interface coupling halves would need to be developed and controlled in a similar manner to the current refuel coupling. This interface would consist of a nozzle portion attached to the servicing hose and a matching

airplane mounted receptacle. The interface would be designed to prevent incorrect connections of other servicing hoses or devices to protect the various airplane systems, including the inerting system. The design would incorporate a frangible self-sealing coupling interface to prevent damage to the aircraft in the event the hose or coupling itself is forcibly removed. An example of this might be a NEA servicing truck driving away still connected to the aircraft interface or a NEA servicing hose being snagged by other service vehicles driving away. The coupling design and materials would be required to be a non-sparking design to prevent ignition sources where fuel is or could be present. This non-sparking requirement would also include all potential failure modes.

As presently envisioned, the interface would include at least one internal check valve. The insertion and engagement of the ground hose end of the interface would actuate this check valve. This would allow NEA pressure into the interface coupling followed by the check valve(s) opening to the fuel tank. The purpose of this timing is to prevent fuel from draining into the hose assembly and allowing the pressure of the NEA to push back the fuel if any has leaked into the manifold assembly. The insertion and engagement of the two halves of the servicing interface could be a manual operation similar to a refueling single point coupling, or an automatic mechanism. The method chosen should be standardized to ensure servicing commonality. The automatic mechanism is preferred from an overall system standpoint to assist less skilled or trained personnel to safely service the inerting system. A witness drain to identify leakage past the isolation or nonreturn valves may also be required here.

Each aircraft manufacturer would have the option of integrating a servicing interface module into their particular model or designing something specific for their airplanes using the standard coupling interface. The NEA servicing interface would ideally be a modular design and assembly that could be produced by an aerospace component supplier. The assembly would consist of the servicing interface for the NEA servicing hose describe above and a generic mounting configuration that would allow easy mounting adaptation to various models. This mounting configuration may include mounts to attach the service doors required in the fairing application. Since all fairings would be different, this service door design would need to be flexible and yet provide some degree of commonality to maximize manufacturing efficiency and minimize cost.

9.1.1 Witness Drains

A witness drain would be required to detect leakage in the double walled portions of tubing exterior to the fuel tank. This could also be accomplished by routing the inter-shroud drains to overboard drain masts if those masts drain while on the ground. This would give ground personnel and the pilots visibility if the double walled tubing (or hose) configurations are leaking fuel. Gaseous leakage would be difficult to detect on a daily basis. A maintenance plan would be required to do leak checks on this double walled tubing at reasonable intervals to ensure the secondary barrier is intact.

9.1.2 Isolation Valve

An isolation valve may be required to isolate the tank from the external tubing. It is envisioned that this valve would be an electrically operated valve and mounted directly to the internal surface of the tank.

9.1.3 Non-Return Valve

A non-return valve (check valve) to prevent backflow of fuel into the NEA supply would be required internal to the center tank at the main NEA manifold penetration into the tank. It is envisioned that this valve could be mounted directly to the tank wall surface if the isolation valve was not required.

9.1.4 Thermal Relief Valve

Thermal relief valves are required to relieve any pressure that may build up in the tubing due to temperatures changes. Thermal relief valves may be incorporated into the other valves or equipment present in the system.

9.1.5 Indication and Control

A control switch and position lamp for the isolation valve may be required. This switch and indicator would be required to be intrinsically safe or environmentally/hermetically sealed in a manner to not present a potential ignition source due to the potential presence of fuel. Any control hardware located near the NEA interface would also be required to be housed or protected to not present a potential ignition source.

9.1.6 Drain Valves

Drain valves may be required in the tubing and/or manifold where locations do not drain fuel to minimize interference with the trapped fuel and the incoming inerting gases. Drain valves would not be necessary where the design could be shown to always clear itself and provide the proper volume of inerting gas.

9.1.7 Placards

Placards would be affixed to those areas requiring cautionary and/or safety instructions, and placards would be provided directly adjacent to the interface coupling servicing installation area. The servicing coupling placard would clearly identify the certified, NEA volume to be loaded on the aircraft. Placards would be clearly readable and of materials consistent with the usage.

9.2 AUXILIARY TANKS

Auxiliary fuel tanks would require similar equipment as the main center tanks in the aircraft. Auxiliary fuel tanks are envisioned to be inerted through the same NEA servicing coupling as the center tanks. As such, the auxiliary tanks could receive their inert gas from the same manifold. Depending on how the system is designed and operated, it may require additional control circuitry for the auxiliary tank isolation valves to control the time the auxiliary tank isolation valves are open. This would be to ensure that a sufficient volume of inert gas is distributed to the auxiliary tank as the center tanks are being inerted. The details of this are presented at this time due to the variability of auxiliary tank systems.

9.3 ADDITIONAL EQUIPMENT REQUIRED

Aircraft designed with crossvented fuel tanks will need to have the vent system design modified and demonstrate methods to minimize NEA exchanges due to the crossventing configurations. This is envisioned as a low cracking pressure bi-directional flapper check valve that is installed in all but one vent passages used for the center tanks. These changes will need to be implemented carefully to take all vent system design issues into account. These changes will also need to account for interaction by auxiliary fuel tanks.

10.0 INSTALLATION REQUIREMENTS

10.1 NEW DESIGN

The design of a ground based inerting system requires the careful and balanced selection of a number of design parameters to optimize the system's performance versus the aircraft servicing time. The prime requirement of the system will be to distribute the NEA to achieve a reduced oxygen concentration to comply with the rule and the specific certification.

No major concerns are seen with the GBI inerting concept, assuming the design is launched in the early phase of the design. During the design cycle the system would be subject to design reviews, safety assessment, zonal analysis, etc. The manifold design, structural penetrations, wiring and service point

location would be worked in the basic design phase. Routing of any electrical controls or circuits associated with any of the equipment used would need to be implemented carefully to not introduce any new hazards. Location of the servicing interface point would need to consider not only the location of the servicing trucks, but be located so as not to introduce additional hazards in the event of a wheels up landing. Accessibility of the servicing interface connection would need to consider the acceptability of servicing steps/platform if necessary.

Installation requirements for all designs will be very similar. Installations for new designs will have the most flexibility to optimize plumbing and its associated placement. It is expected the NEA manifold would be mounted as close to the top of the tank as possible. This would be to ensure that the maximum mixing and venting of the tank gases occurs to efficiently purge the fuel tanks of oxygen with the minimum quantity of NEA in any refueling scenario. Effort to minimize the formation of fuel collection sites within the manifold should be made. This may include drain valves in those designs that may not be capable of clearing these fuel obstructions through the normal NEA servicing procedures and the servicing pressures available.

10.2 IN-PRODUCTION

Optimum manifold design in terms of weight and location may not be possible due to other systems installed and limitations on location of structure penetrations. Optimum plumbing configurations and lengths may not be possible due to the restrictions on getting plumbing into the airplane after assembly. Modifications to tank venting arrangements may be required on certain aircraft types. This will require additional design and certification activity over and above that required to demonstrate the effectiveness of the modification for inerting the tank. Depending on the location of the servicing interface point, redesign of a section of the external aircraft body fairing may be required including the introduction of a specific access panel to gain access to the servicing point. Airline spares will be impacted.

10.3 RETROFIT

Concerns expressed for the in-production design are equally applicable. If modifications to the tank installation or areas around the fuel tank have been made to the aircraft since the original delivery then further additional design work and adaptations may be required.

10.4 AUXILIARY TANK INSTALLATIONS

Generally, the comments above also apply to auxiliary tanks. Several additional concerns also apply:

- The need for double walled tubing in the pressurized areas will further complicate tube routing in areas where space is already constrained by other systems.
- If more than one auxiliary tank is installed it will be necessary to balance the flow of NEA between the tanks. This may require a NEA volume greater than that currently envisaged of 1.7 times the total ullage or other design changes unknown at this time.
- Some auxiliary tanks include bladders inside the tanks. This will complicate redesign because of the need for new bladders to accommodate new tubing penetrations and routing in the tank.
- Modification of cargo bay liners will be required, due to the new plumbing penetrations.

11.0 SYSTEM IMPACT ON OTHER SYSTEMS

Because the NEA may be dissolved in the fuel differently than other gases, there may be some impact of other systems in the aircraft. Those impacts must thoroughly investigated to ensure a detrimental effect is not introduced by these inerting systems. The detailed testing required to ensure safe and proper operation of these systems is beyond the scope of this report, other than to address and note these concerns in a general manner. The concerns are as follows:

11.1 PUMP PERFORMANCE

NEA coming out of solution from the fuel, particularly when the aircraft climbs, may be different from the evolution of air or other existing dissolved gases. Those differences most likely would be explained as a function of bubble size and/or the rate the bubbles are evolving from the fuel. The ability of the engine pumps, fuel boost pumps and ejector style pumps to successfully prime, pump, and reprime in a predictable manner identical to past performance is essential. If it were demonstrated that this was not the case, then all fuel pumping equipment would require re-qualification at considerable expense. Further, these differences would require evaluation of engine feed operational issues and it is likely to require re-certification testing, again at considerable expense.

11.2 IMPACT ON FUEL QUANTITY INDICATION SYSTEM (FQIS) PERFORMANCE

The effects of nitrogen inerting on the various fuel measurement techniques are not fully understood at this time. The process of injecting the NEA into the fuel tanks may have effects including:

- Introducing larger quantities of dissolved nitrogen into the fuel
- Potential for displacing other dissolved gases in the fuel
- Causing the formation of bubbles both in the fuel and on the fuel surface
- Causing the bubbles to manifest themselves differently than before
- Changing the properties of the fuel

Detailed testing of the chemical and physical effects of nitrogen inerting in this new environment should be done to insure that the functional integrity of the various fuel measurement techniques are not degraded. The consequences of these changes may effect the accuracy or reliability of the specific FQIS measurement techniques and equipment used. That would need to be carefully studied and characterized to ensure there were no side effects in-service. That detailed testing is beyond the scope of this report.

11.3 IMPACTS ON CROSS VENTED SYSTEMS

“Cross vented” venting systems, or those that have center tank vents that run out to both wing tips, appear to be less desirable for inerting systems. The potential for flow through the tanks between the two vent locations can produce a scavenging effect that will cause the ullage to exchange with the outside air in a short period of time. This increases the oxygen content in the tank to rise as the outside air is brought in. Those airplanes that have these venting systems would be required to design a means to retain low oxygen contents in the ullage space.

11.4 POTENTIAL IMPACT ON FUEL PROPERTIES

Through the process of inerting the fuel tank ullage, the lighter fractions contained in the fuel are removed. The effect of this change on fuel properties has not been characterized for the engines and their performance. Detailed testing to characterize this issue is beyond the scope of this report.

12.0 SYSTEM SAFETY

The primary focus of the GBI design team was to carefully and thoroughly evaluate ground based inerting systems with a heavy emphasis on not introducing new safety hazards for either personnel or the airplanes. While the safety impacts of the GBI system are discussed in detail elsewhere in this report, the primary safety concerns of this system are stated here again for reference. The safety concerns are primarily associated with the following:

- The use of nitrogen, NEA, or other oxygen displacing gas in confined spaces.
- The flow of oxygen depleted gases from the aircraft wingtip vents.

- Overpressurization of the wing structure due to malfunction of the ground or airplane mounted inert gas pressurization equipment.
- Minimizing new safety hazards associated with a “wheels up” landing. This is primarily a servicing interface location issue.
- Minimizing new ignition source hazards associated with incorporation of a GBI system. Non-sparking materials and components at the servicing interface coupling, careful use of electrical components, and minimizing new electrostatics issues due to the ullage purging are examples.
- Safeguards to prevent fuel spillage

13.0 SYSTEM WEIGHT

The estimated weight required for each ARAC aircraft is outlined below to assess the system impacts on the aircraft performance and it’s associated economic impact. Weights for the ARAC Turbofan, Turboprop and Bizjets are estimates based on the ARAC Small aircraft data as detailed information on the actual systems and configurations were not known. The ARAC Turboprop is not included below because that configuration does not have a center tank by definition. The ARAC Bizjet does not have a center tank by definition, but information that some Bizjets have a center tank in reality became available late in the study and these configurations are shown as well. Figure 13.0-1 lists the estimated weights for the various systems.

ARAC Standard Configuration Model	Total Weight US Pounds	Total Equipment Weight US Pounds	Total Plumbing Weight (including couplings) US Pounds	Total Other Installation Weights (including brackets, bonding jumpers, structure modifications, and hardware) US Pounds)
Large Aircraft	54	6	36	12
Medium Aircraft	34	6	20	8
Small Aircraft	22	6	10	6
Turbofan	15	5	7	3
Turboprop	---	---	---	---
Bizjet	15	5	7	3
Aux tank for Large	45	3	39	3
Aux tank for Medium	45	3	39	3
Aux tank for Small	47	13	27	7

Note: 1. Auxiliary tank weights listed are for the tank equipment and its associated external manifold equipment only. Does not include the associated additional airplane structural and systems weights.

Note: 2. Auxiliary tank weights for the Small aircraft is based on tanks located in both the front and the rear cargo areas of the aircraft.

Figure 13.0-1. Estimated System Weights

14.0 EVALUATION OF REDUCTION IN EXPOSURE TO FLAMMABLE ATMOSPHERE

14.1 REDUCTION IN EXPOSURE TO FLAMMABLE ATMOSPHERE ANALYSIS

The methodology of analyzing flammability exposure is explained in the main body of this report in Section 4.2 Flammability. Utilizing this modeling approach, the baseline flammability for the Large, Medium and Small Transport categories were performed and the corresponding values are shown in figure 14.1-1 below. As noted in the discussion on modeling, these values do not represent any specific airplane, only a generic configuration selected to represent an airplane in this category.

Incorporating GBI on these airplanes is analyzed based on the following assumptions:

- Every airplane is inerted with the volume of 95% NEA necessary to reduce the oxygen content to 8% with an empty tank. Thus, flights with a partially full center tank actually start at less than 8% oxygen.

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- The inerting is a step function inserted at halfway through the “time at gate after refueling”. Additional modeling refinement was not made to model the actual inerting flow time or a random distribution of when the inerting may occur during the gate time, as would occur in actual implementation. However, it is expected that the results presented here are similar.
- The model assumes no loss of nitrogen during steady state cruise. Depending upon the openness of the tank venting and the duration of the flight, there may be some loss not accounted for in this analysis.

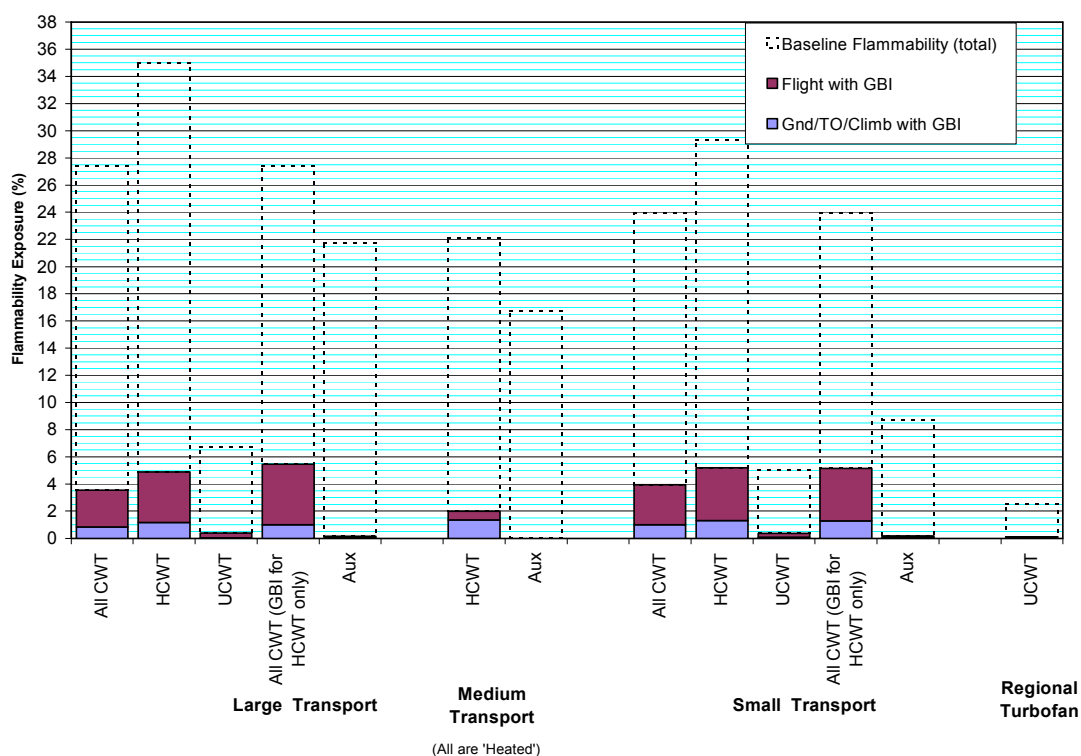


Figure 14.1-1. Flammability Exposure Results for the Ground-Based Inerting System

The results of the analysis are that the fleet wide (All CWT) Flammability Exposure after GBI is as shown in figure 14.1-1 for the Large, Medium and Small Transports. The “All CWT” values represent a combination (per the ARAC estimated distribution) of the Heated Center Wing Tanks (HCWT) and the Unheated Center Wing Tanks (UCWT) values. Also shown are the individual values for the HCWT and the UCWT generic airplanes. The difference in the exposures between the different sizes of transport airplanes is a function of the generic definition of the models, and demonstrates the variation from model to model that would exist due to difference in tank sizes, mission profiles and other variables. Also shown is the effect of GBI on an ARAC defined Regional Turbofan airplane, which has an unheated center tank.

Per the Tasking Statement, GBI has been analyzed only for tanks which do not cool at a rate equivalent to a wing tank. Therefore, wing tanks, the regional turboprops, and the business jets are not included in the analysis as they do not include tanks that fit this criterion.

The tasking statement also asks for the effect of limiting GBI to airplanes with only Heated Center Wing Tanks (HCWT). As shown in the numbers, the largest benefit is for HCWT airplanes, as the baseline flammability of the UCWT airplanes is already approximately the same as the HCWT with GBI. Therefore, limiting GBI to airplanes with HCWTs would result in only a modest increase in fleet wide flammability exposure. Note that GBI for only HCWTs, which is defined as Scenario 11 in the Estimating

and Forecasting section (Section 11.0) of the main report, has been used in the Executive Summary Information (Section 1.0).

Auxiliary tanks were also evaluated and the results are also shown in Figure 14.1-1. As shown, for airplanes with unpressurized auxiliary tanks, GBI would significantly reduce the flammability. The use of pressurized auxiliary tank systems may be an alternative method of reducing the flammability as discussed below.

14.2 ALTERNATE METHOD FOR REDUCTION OF FLAMMABLE ATMOSPHERE FOR AUXILIARY FUEL TANKS

Estimated Percentage of Fleet equipped with Auxiliary Tanks:

ARAC Transport Category	Heritage Boeing	Heritage MDC	Airbus	Total Fleet Percent	Fleet Percent Ambient Pressure	Fleet Percent Pressurized Tanks
Large	1%	15%	-	5%	5%	-
Medium	0.1%	-	5%	2.5%	-	2.5%
Small	5%	20%	4%	8%	5%	3%

Flammability is highly dependent upon the usage of the auxiliary tank. While only a fraction of the fleet has auxiliary tanks, it is estimated that the usage of the tanks on the specific airplanes equipped with auxiliary tanks would be similar to the overall usage of center tank fuel for the entire fleet. Therefore, we are assuming 20% of flights on airplanes equipped with auxiliary tanks load some fuel in the auxiliary tanks.

Flammability is dependent on tank ullage pressure. The pressure decrease associated with cruise altitude results in an effective decrease in the Lower Flammability Limit (LFL) temperature of about 40 degrees F. By maintaining the tank pressure at a lower altitude, the LFL decrease is less. Designs that maintain auxiliary tank pressure exist. For the purposes of this estimate, we have assumed they maintain a 20,000 foot altitude pressure during cruise. Auxiliary tanks are not exposed to temperature increase from A/C packs and are located in the cargo areas. Thus, flammability is a function of the ground ambient temperature, the cruise cargo area temperature and the tank ullage pressure.

Given the above factors, the baseline flammability of auxiliary tanks are calculated as:

ARAC Transport Category	Fleet Size - Ambient Pressure Aux Tanks	Flammability Exposure -Ambient Pressure Aux Tanks		Fleet Size - Pressurized Aux Tanks	Flammability Exposure - Pressurized Aux Tanks (20,000 feet)
Large	5%	22%		-	3.0%
Medium	-	17%		2.5%	2.2%
Small	5%	9%		3%	3.2%

Finally, maintaining auxiliary tank pressure altitude at or below 10,000 feet can further limit the LFL decrease at cruise and thus limit flammability.

ARAC Transport Category	Flammability- (10,000 feet) Pressure Tanks
Large	0.3%
Medium	0.4%
Small	0.6%

Thus, an auxiliary tank pressurized to 10,000 foot altitude is approximately equivalent to GBI. It is expected that modifying or replacing auxiliary tanks to utilize pressurized systems limited to 10,000 foot

ambient pressure altitudes would be an acceptable (and potentially preferred) alternative to incorporating GBI on auxiliary tanks.

14.3 BACKGROUND INFORMATION ON FLAMMABILITY

The critical combustion concentrations are known as the limits of flammability of the system and are defined as the fuel-lean, or lower flammability limit (LFL), and the fuel-rich, or upper flammability limit (UFL). When fuel is raised above the LFL, the fuel/air vapor mixture it produces (once it reaches an equilibrium state, will be flammable). If the temperature is too high, the fuel/air vapor mixture may be too rich (too much fuel) to be flammable. Likewise, when the mixture temperature is decreased, the fuel condenses and the mixture decreases. See figure 14.3-1 for an illustration of these concepts for JP-8, which is similar to Jet A and Jet A1 fuel used for commercial jet aviation.

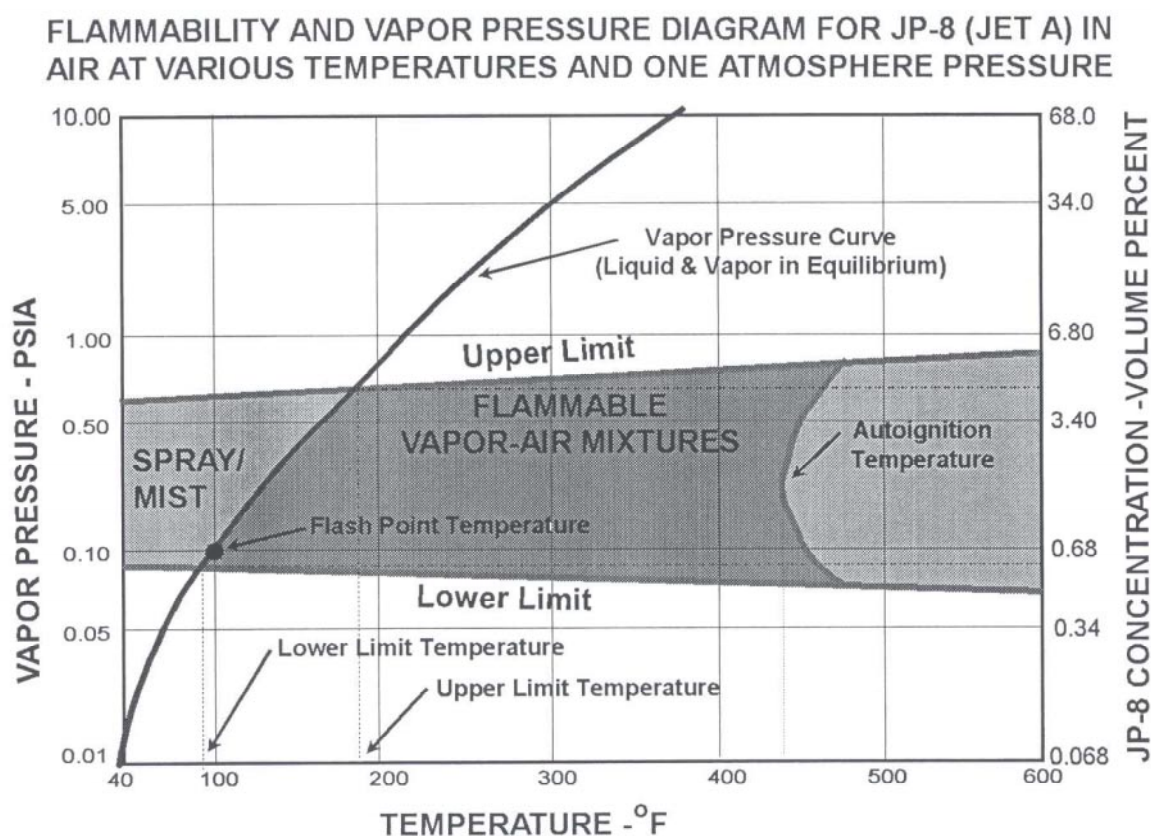


Figure 14.3-1. JP-8 (Jet A) Flammability and Vapor Pressure

Regarding Figure 14.3-1, it should be noted that the flash point of the fuel varies with each batch, but the specified minimum for Jet A is 100F. The flash point of the fuel is determined by a closed cup method, which correlates somewhat with the LFL. This test is conducted at ambient conditions, the amount of oxygen is fixed and the ignition source is specified. Note that the flash point of a given batch of fuel is about 10F above the LFL. The flash point will decrease with a decreasing ambient pressure. Correspondingly, the pressure, and therefore altitude, affect the LFL and UFL's. This is illustrated in figure 14.3-2 for several aviation fuels. As the pressure in the fuel tank is reduced during ascent, the effective flammability range is lowered as is shown in figure 14.3-2.

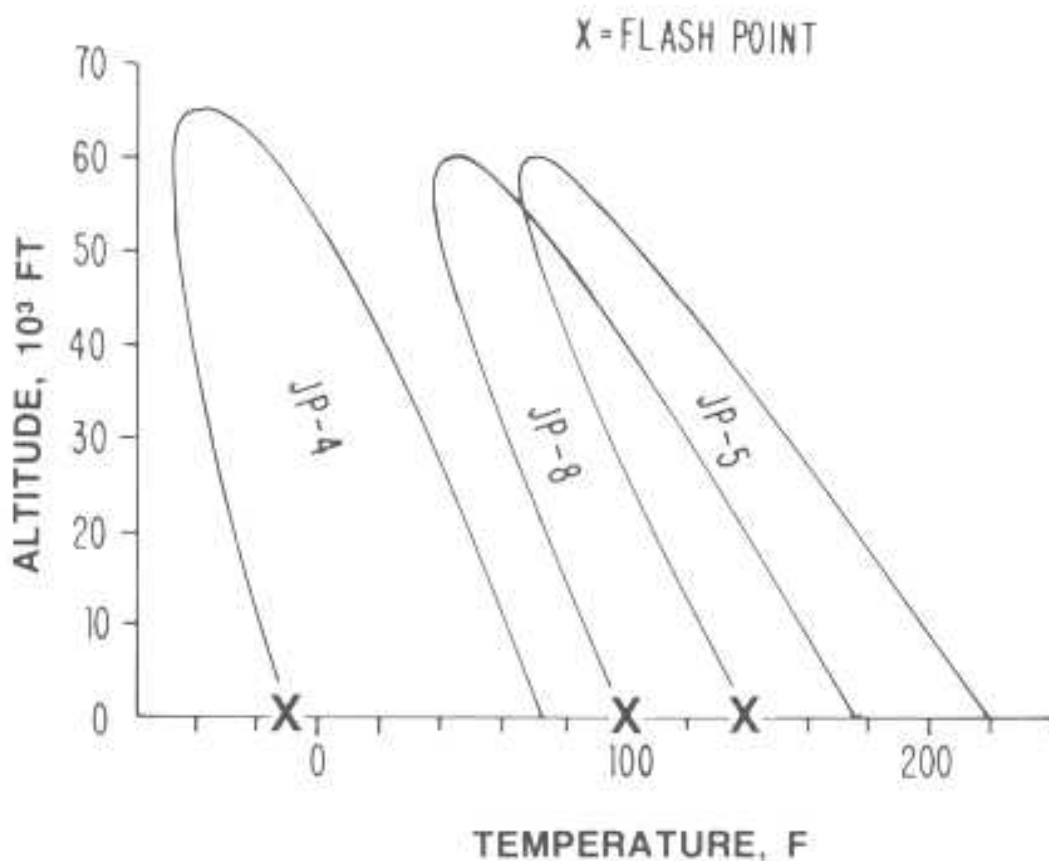


Figure 14.3-2. Aircraft Fuel Flash Point as a Function of Altitude and Temperature

14.3.1 Inerting

Figure 14.3.1-1 shows the recommended oxygen percentage for aviation fuels is 9% which indicates no explosions are possible if the level of oxygen inside the fuel tank is 9% or lower. The “maximum recommended oxygen percentage” applies to maintaining an inert atmosphere for protection against unexpected or unlikely sources of ignition. Further by starting out at a lower oxygen content, the inert level will remain longer in the ullage. This level should be maintained for as long as possible throughout the flight profile.

**Maximum Permissible Oxygen Percentage to Prevent
Ignition of Flammable Gases and Vapors Using Nitrogen and
Carbon Dioxide for Inerting**

	N-Air		CO ₂ -Air	
	O ₂ Percent Above Which Ig- nition Can Take Place	Maximum Recom- mended O ₂ Percent	O ₂ Percent Above Which Ig- nition Can Take Place	Maximum Recom- mended O ₂ Percent
Acetone	13.5	11	15.5	12.5
Benzene (Benzol)	11	9	14	11
Butadiene	10	8	13	10.5
Butane	12	9.5	14.5	11.5
Butene-1	11.5	9	14	11
Carbon Disulfide	5	4	8	6.5
Carbon Monoxide	5.5	4.5	6	5
Cyclopropane	11.5	9	14	11
Dimethylbutane	12	9.5	14.5	11.5
Ethane	11	9	13.5	11.0
Ether	—	—	13	10.5
Ether (Diethyl)	10.5	8.5	13	10.5
Ethyl Alcohol	10.5	8.5	13	10.5
Ethylene	10	8	11.5	9
Gasoline	11.5	9	14	11
Gasoline 73-100				
Octane	12	9.5	15	12
100-130 Octane	12	9.5	15	12
115-145 Octane	12	9.5	14.5	11.5
Hexane	12	9.5	14.5	11.5
Hydrogen	5	4	6	5
Hydrogen Sulfide	7.5	6	11.5	9
Isobutane	12	9.5	15	12
Isopentane	12	9.5	14.5	11.5
JP-1 Fuel	10.5	8.5	14	11
JP-3 Fuel	12	9.5	14	11
JP-4 Fuel	11.5	9	14	11
Kerosene	11	9	14	11
Methane	12	9.5	14.5	11.5
Methyl Alcohol	10	8	13.5	11
Natural Gas (Pittsburgh)	12	9.5	14	11
Neopentane	12.5	10	15	12
n-Heptane	11.5	9	14	11
Pentane	11.5	9	14.5	11.5
Propane	11.5	9	14	11
Propylene	11.5	9	14	11

Notes to Table

1. Data in this Table were obtained from publication of the U.S. Bureau of Mines.
2. Data were determined by laboratory experiments conducted at atmospheric temperature and pressure. Vapor-air inert-gas samples were placed in explosion tubes and exposed to a small electric spark or open flame.
3. In the absence of reliable data, the U.S. Bureau of Mines or other recognized authority should be consulted.
4. The "Maximum Recommended O₂ Percent" applies only to maintaining an inert atmosphere for protection against unexpected or unlikely sources of ignition. Much higher factors of safety are required for conditions where sources of ignition are deliberately applied such as hot work. See Purging, Paragraph 223.

Figure 14.3.1-1. Maximum Oxygen Content for Inerting System Flammability as a Function of Fuel Type

Figure 14.3.1-2, 14.3.1-3 and 14.3.1-4 are included for additional reference.

Figure 14.3.1-2 contains data for military gun fire testing on inert tanks. While this data is included for reference, the military data demonstrates that the 9% oxygen level is supportive of a non-explosive, safe, and survivable environment.

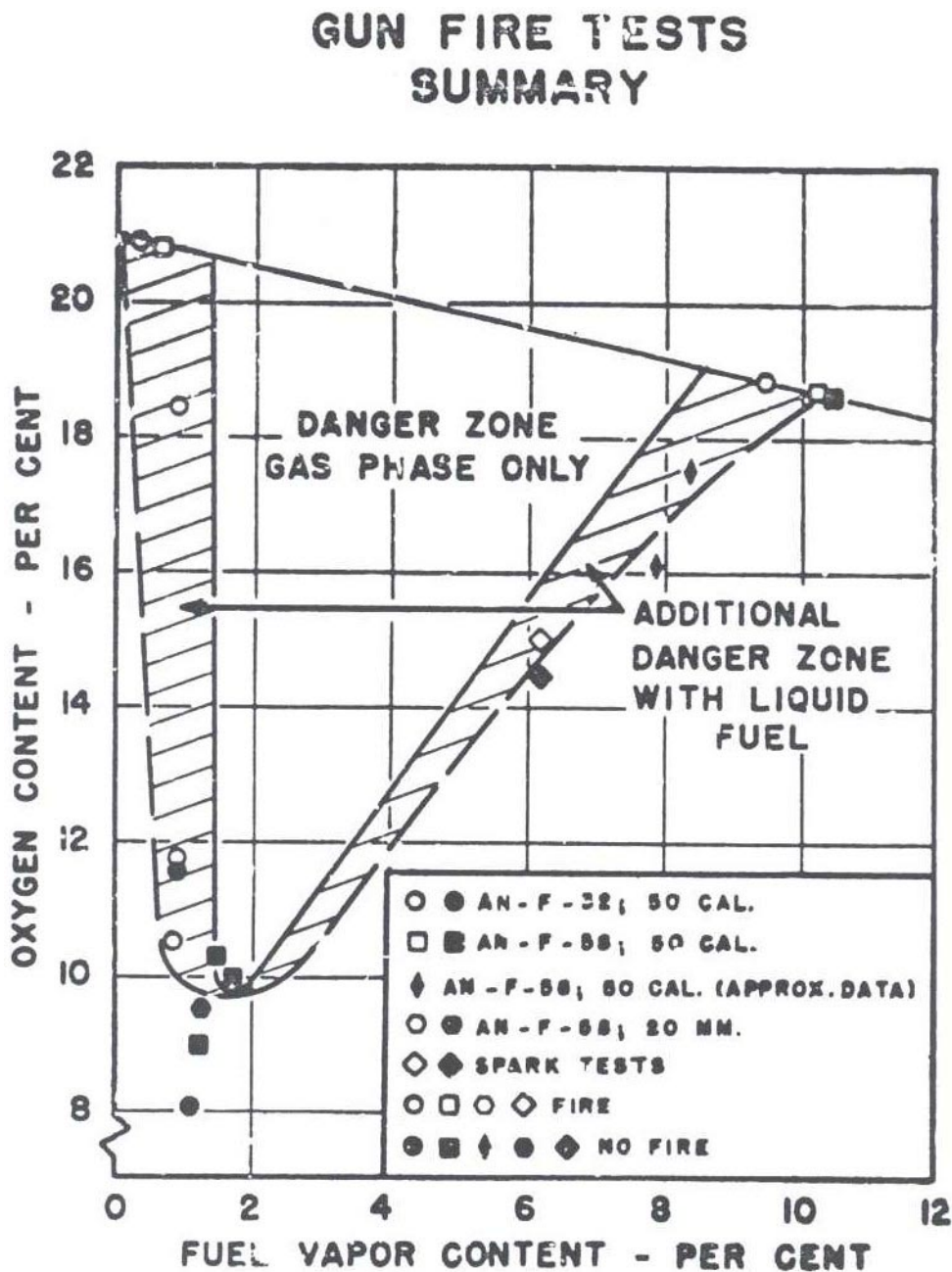


Figure 14.3.1-2. Tank Combustibility With Gun Fire as a Function of Oxygen and Fuel Content

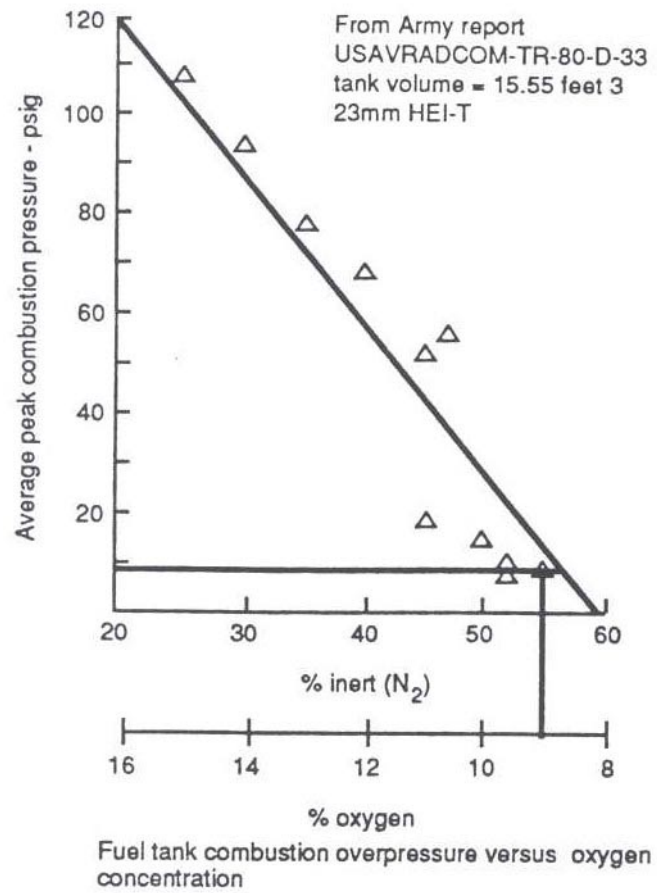
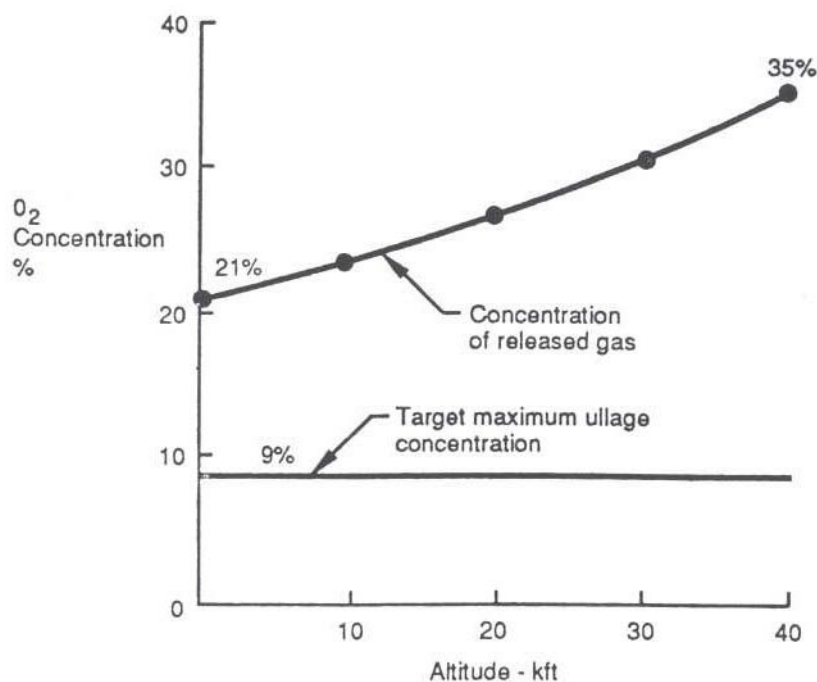


Figure 14.3.1-3. Fuel Tank Combustion Overpressure Versus Oxygen Concentration



Unprotected fuel tank ullage oxygen concentration versus altitude

Effect of Ullage Oxygen Concentrations on Fuel Tank Vulnerability

Figure 14.3.1-4. Effects of Dissolved Oxygen Released From the Fuel on Ullage Oxygen Concentrations

After an evaluation of additional literature, it is evident that a minimum 9% oxygen level should be considered for complete fuel tank inerting. The 9% oxygen level (or lower) gives a longer sustained inert level throughout the flight profile. If the 9% is to be utilized rather than the 10% level mentioned in the Tasking Statement, then it would only increase the volume of NEA to be added. It would not fundamentally change the system design concept

15.0 CERTIFICATION COMPLIANCE

Certification and compliance to a new fuel tank flammability rule utilizing ground based inerting systems as the method of compliance would likely be based on demonstration testing. The certification of each aircraft model, or variation thereof, would likely require actual aircraft testing on each new, variation, or retrofit design. The purpose of the testing would be to verify that the operation of the GBI system on that particular aircraft would result in reducing the oxygen level below a value set forth in the rule in all areas of the fuel tanks for which the rule required. The testing would also validate the quantity and quality of NEA required for the particular aircraft manifold design. This would establish the certified volume of NEA at a particular purity and pressure range that would be required to be loaded into the aircraft to meet the requirements of the rule. In addition, it is likely that flight testing would be necessary on each aircraft design type to validate that the inert levels are maintained adequately during flight to demonstrate compliance with the new rule.

Other means of compliance certification may be utilized if they can be shown to accurately represent, model, and duplicate the inerting process in actual aircraft testing. Any modeling system would require a demonstration in parallel with an aircraft inerting system testing to validate the modeling system. This alternate method of showing compliance to the rule would likely only be accepted after FAA approval and validation with actual aircraft testing.

It is assumed that guidance on the detailed parameters associated with the certification testing would be discussed in the Advisory Circulars associated with the new rule. The Advisory Circular would also provide guidance on a method to certify the aircraft model. Testing, test equipment, and test procedures would be conducted in a manner consistent with that prescribed in the Advisory Circular, unless the associated FAA Certification Office accepted another means of demonstrating compliance. Compliance of each aircraft model would likely require instrumentation of an actual aircraft fitted with the new ground based inerting equipment to be tested. Testing would then be conducted monitoring the oxygen concentration in the fuel tanks applicable to verify that the concentration does not exceed the maximum levels set forth in the rule. Guidance on the oxygen sensor placement, distribution, and mounting in the fuel tanks being tested would also be provided in the Advisory Circular.

It is expected that each new aircraft model, or variation thereof, would be required to carry adequate placarding to insure the servicing of the ground based inerting system meets the parameters required to insure the system operates per its original certification.

If an aircraft is subsequently changed or modified by Supplemental Type Certificate, or other change medium, after the original issuance of the type certificate, the new or affected GBI system operation and effectiveness would require re-testing to show the proper oxygen levels are obtained with the new design. Revised Placarding would be required to clearly identify the new configuration and its associated new total NEA requirements. Placarding on same or similar models that may have minor changes due to certification activities beyond the original certification should employ methods to clearly make the certification differences known to those servicing the aircraft. These differences could be, as an example, color or size variations in the placarding.

To demonstrate that the reduced oxygen level has been achieved and is retained in the tank as predicted, it is anticipated that the following series of ground and flight tests will be required:

1. For center tank installations, the operation of the NEA distribution system will need to be demonstrated over a range of initial tank conditions of:
 - a. Tank at unusable quantity, but not sumped
 - b. Tank at 50% capacity
 - c. Tank maximum declared volume with required expansion space
2. It will also be necessary to demonstrate the ullage conditions when refueling is carried out simultaneously with loading NEA. The objective of the test would be to show that the required oxygen concentration is achieved in the ullage space when the specified quantity of NEA is added even as the refueling process is taking place. For this test where refueling and NEA are added simultaneously, the objective would be to demonstrate correct dispersion and concentration of the NEA is achieved when the specified NEA quantity has been added within a time interval shown by analysis, or additional testing, as an acceptable range.
3. For auxiliary fuel tank installations where the vent system is through the center tank, the same series of center tank tests would be necessary to demonstrate the auxiliary fuel tank inerting system. The exception to this is that testing would be an additional requirement to demonstrate that the auxiliary tank system meets the requirements regardless of the level of center tank fuel. The operational characteristics of the individual systems would determine the extent of their test program in order to fully demonstrate the system operation.
4. Flight testing to demonstrate the fuel tank retains the required oxygen concentration over a determined test period including a take off and climb will be required. During the climb the effects of maneuvers will need to be demonstrated. The extent of this testing is unknown at this time, but most likely the test would be performed starting with the inerted tanks initially empty, partially full, and then full. For aircraft with auxiliary tanks, a similar series of tests may need to be performed. The

specifics of that testing is also unknown at this time. During these flight tests a means of continuously sampling the oxygen content of the ullage will be required.

16.0 PRO AND CONS OF THE SELECTED DESIGN CONCEPT

Pros

- Proposed system design concept is simple with the least effect on airplane.
- Involves little technical complexity
- Utilizes current technology components
- Does not introduce any new installation technology
- System operation is straightforward in that it is not sequenced with the refuel operation and does not require any knowledge of the actual fuel load.

Cons

- Does not remain inert for 100% of the flight cycles. Introduction of air due to fuel consumption, and ground time after landing but before inerting, may result in still being flammable on hot days.
- Dependent on significant airport infrastructure
- Low NEA supply pressure required to avoid over pressurizing the aircraft tanks
- New standard required to be developed for the aircraft interface coupling
- Amount of NEA supplied may be in excess of that required to achieve the inert levels when the tanks is already partially, or completely full.
- Requires special / unique maintenance practices.
- Increased volatile organic compounds (VOC) emissions.

17.0 MAJOR ISSUES AND RESOLUTIONS

- GBI use on aircraft on is dependent upon high capital investment for airport NEA production and servicing systems, not currently available at any airports.
- To allow the aircraft to be purged from the ground based distribution system at any airport location a new standard interface coupling must be developed and controlled by a recognized authority. The timescale for acceptance of this standard and the availability of hardware must be compatible with the regularity requirements.
- The correct purging of the tank ullage is dependent upon the performance of the ground supply. A specification will be required to control pressure /flow performance and integrity of the ground equipment. The required volume to correctly purge the tank ullage will be defined following aircraft tests. The specification of the ground equipment will therefore need to be established before the aircraft tests can be performed.
- Some of the ground equipment requirements (i.e., delivery pressure) are driven by the need to consider the potential requirements to retrofit the system onto existing aircraft. The ground equipment is must be defined so that it does not constrain future aircraft designs.

Appendix D

Onboard Inerting Designs Task Team Final Report

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